WORKING DRAFT
Forest Resources & Practices
Region II-III Reforestation
Annotated Bibliography
July 7, 2014

◆ Contents ◆

GENERAL

◆ **Barrett, Tara M.; Christensen, Glenn A., eds. 2011.** Forests of southeast and south-central Alaska, 2004–2008: five-year forest inventory and analysis report. Gen. Tech. Rep. PNW-GTR-835. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 156 p.

Author abstract. This report highlights key findings from the most recent (2004–2008) data collected by the Forest Inventory and Analysis program across all ownerships in southeast and south-central Alaska. We present basic resource information such as forest area, ownership, volume, biomass, carbon sequestration, growth, and mortality; structure, and function topics such as vegetation and lichen diversity and forest age distribution; disturbance topics such as insects and diseases, yellow-cedar decline, fire, and invasive plants; and information about the forest products industry in Alaska, the potential of young growth for timber supply, biofuels, and nontimber forest products. The appendixes describe inventory methods and design in detail and provide summary tables of data and statistical error for the forest characteristics sampled.

◆ **Graham, J.S., and P.A. Joyner. 2011.** Tree planting in Alaska. Tree Planters Notes. 54(2):4-11

Author abstract. Tree planting for reforestation in Alaska has been modest compared with other timber-producing States and has never exceeded 1 million trees a year. Most timber harvest occurs in southeast Alaska, where natural regeneration is usually prolific and logistical costs are very high. Tree planting has been more suited to the boreal forest, where white spruce (*Picea glauca* (Moench) Voss) regeneration is sought and natural regeneration can be problematic. In the 1990s, a large spruce bark beetle (*Dendroctonus rufipennis* Kirby) epidemic on the Kenai Peninsula stimulated tree planting. Planting for poplars (*Populus* spp.) may develop near rural communities as biomass energy develops. Tree planting by homeowners and communities has been growing, which has resulted in the development of several community tree inventory programs and management plans. In 2010, approximately 1,600 trees were planted on municipal property or in public rights-of-way in Anchorage, and a much higher number is estimated to have been planted on private and other public land.

◆ **Ott, R.A. 2005.** Summaries of management and research activities related to Alaska's boreal forests. 2nd ed. Alaska Northern Forest Cooperative. Unpublished. 119 pp.

Compiler abstract: This document compiles summaries of published and unpublished management and research activities including information in the following categories:

- Climate variability and forests
- Fire management
- Forest community classification,
- Forest health,
- Forest inventory
- Site index
- Tree regeneration
- Tree thinning
- Tree volume equations
- Wildlife

◆ **Puettmann, K.J., and Ammer, C., 2007.** Trends in North American and European regeneration research under the ecosystem management paradigm. Eur. J. For. Res. 126, 1-9.

Author abstract. Forest management on many ownerships in North America and Europe has shifted toward the ecosystem management paradigm. The associated shift toward multiple management objectives and focus on natural development patterns should also be reflected in regeneration research efforts. As new information needs arise, research questions and approaches should be evaluated whether they are still appropriate. Specifically, spatial and temporal scales of research studies need to be expanded to accommodate complex sets of management objectives and constraints, rather than being focused on optimal tree regeneration. At the same time, silviculturists are asked to utilize natural trends as a guide for management, but most natural disturbance studies have focused on stand structures and not the regeneration processes. Criteria commonly used to describe disturbance regimes need to be modified to better guide regeneration research efforts under the ecosystem management paradigm.

SILVICS

◆ **Adams, P.C. 1999.** The dynamics of white spruce populations on a boreal river floodplain . Unpubl. PhD Thesis, Duke University. 178 pp.

Author abstract. Studies of forest development on river floodplains in interior Alaska have asserted that succession is linear and directional. Beginning with the invasion of willows on newly formed silt bars, subsequent fluvial depositional builds terraces of increasing height and distance from the river on which successive communities of alder, balsam poplar, white spruce, and eventually black spruce develop. This classical model assumes that primary succession is a deterministic autogenic process in which early successional species facilitate the establishment of late successional species through environmental modification. I focused on the dynamics of white spruce establishment and growth in this successional environment. My primary objective was to describe boreal floodplain white spruce forests and the major environmental and biotic constraints on their development. I examined factors affecting the age, growth and spatial structure of white spruce populations across successional sere. Ecosystem processes on the Tanana River floodplain are closely linked to fluvial processes, and these in turn are directed by climate. Patterns of deposition and erosion resulting in the building and removal of successional terraces are functions of the climate controlled river discharge fluctuations, and are neither continuous nor directional. White spruce occurs as seedlings, saplings, and seed-producing trees throughout the primary successional sequence, and its age structure reflects past variation in recruitment and mortality rates. Successful seedling establishment is episodic and correlated with a combination of interacting environmental and biotic factors, including silt deposition accompanying floods, seed production and dispersal, and herbivory of seedlings by snowshoe hares. Both herbivory and low light under canopies reduce seedling height growth. The relative influence of some of these factors changes through succession because of interactions with the developing vegetation. Radial growth patterns of mature floodplain white spruce trees differ from those of nearby upland trees in their reduced sensitivity to climate variability because of the high water table on the floodplain. Although elements of the classic facilitation model of succession are consistent with some of my results, much of the spatial and temporal variability in patterns of white spruce establishment and growth can be attributed to episodic environmental and biotic factors throughout the succession.

◆ **Brassard, B.W., Chen, H.Y.H., 2006**. Stand structural dynamics of North American boreal forests. Crit. Rev. Plant Sci. 25, 115-137.

Author abstract. Stand structure, the arrangement and interrelationships of live and dead trees, has been linked to forest regeneration, nutrient cycling, wildlife habitat, and climate regulation. The objective of this review was to synthesize literature on stand structural dynamics of North American boreal forests, addressing both live tree and coarse woody debris (CWD) characteristics under different disturbance mechanisms (fire, clearcut, wind, and spruce budworm), while identifying regional differences based on climate and surficial deposit variability. In fire origin stands, both live tree and CWD attributes are influenced initially largely by the characteristics of the stand replacing fire and later increasingly by autogenic processes.

Differences in stand structure have also been observed between various stand cover types. Blowdown and insect outbreaks are two significant non-stand replacing disturbances that can alter forest stand structure through removing canopy trees, freeing up available growing space, and creating microsites for new trees to establish. Climate and surficial deposits are highly variable in the boreal forest due to its extensive geographic range, influencing stand and landscape structure by affecting tree colonization, stand composition, successional trajectories, CWD dynamics, and disturbance regimes including regional fire cycles. Further, predicted climate change scenarios are likely to cause regional-specific alterations in stand and landscape structure, with the implications on ecosystem components including wildlife, biodiversity, and carbon balance still unclear. Some stand structural attributes are found to be similar between clearcut and fire origin stands, but others appear to be quite different. Future research shall focus on examining structural variability under both disturbance regimes and management alternatives emulating both stand replacing and nonstand replacing natural disturbances.

◆ **Brown, K. R., D.B. Zobel, and J.C. Zasada. 1988.** Seed dispersal, seedling emergence, and early survival of Larix laricina (duroi) k. koch in the Tanana Valley, Alaska . Canadian journal of forest research 1988, v. 18, no. 2 (Mar. 1988) pp. 306-314.

Author abstract. The seasonal and spatial patterns of seed release, germling emergence, and early survival of *Larix laricina* (DuRoi) K. Koch were studied in 1980–1981 near Fairbanks, Alaska. Dispersal was studied on one wetland site. Seedling emergence and 1-year survival were studied on three wetland microsite types (troughs, feathermoss, and tussock tops, located at increasing elevations above permafrost) and in mineral soil and undisturbed feathermoss seedbeds in a mature *Picea glauca* stand of alluvial origin. Approximately 95% of the viable *Larix* seed from the 1980 cone crop fell by November 1980. Spatial distribution of seed away from the stand was erratic because of variable winds and the presence of a single *Larix* away from the stand edge. Average dispersal distances were less than those reported for other coniferous species. Emergence and early survival in both site types were affected by seedbed type. In the alluvial stand, germination and 1-year survival were greater on mineral seedbeds than on feathermoss. Emergence began in mid-July, well after minimum temperatures required for germination had been reached; timing appeared to be related to differences in volumetric moisture contents of the two seedbed types. Although cumulative totals of emergence and mortality did not differ between microsite types in the wetland, seasonal patterns of each differed with microsite. Emergence in troughs was delayed until early July by cold seedbed temperatures; increased precipitation in mid to late July raised the water table and flooded newly emerged seedlings in trough microsites but moistened feathermoss sufficiently to promote germination. Variation in emergence and mortality was high within a given microsite type.

◆ **Burns, R.M. and B.H. Honkala, tech. coordinators. 1990.** Silvics of North America: v.1. Conifers; v.2. Hardwoods. U.S. Forest Service, Washington, DC. Agric. Handbook 654. 877 p.

Author abstract. The silvical characteristics of about 200 forest tree species and varieties are described. Most are native to the 50 United States and Puerto Rico, but a few are introduced and naturalized. Information on habitat, life history, and genetics is given for 15 genera, 63 species, and 20 varieties of conifers and for 58 genera, 128 species, and 6 varieties of hardwoods. These represent most of the commercially important trees of the United States and Canada and some of those from Mexico and the Caribbean Islands, making this a reference for virtually all of North America. A special feature of this edition is the inclusion of 19 tropical and subtropical species. These additions are native and introduced trees of the southern border of the United States from Florida to Texas and California, and also from Hawaii and Puerto Rico.

◆ **Chrimes, D., 2004**. Stand development and regeneration dynamics of managed uneven-aged Picea abies forests in boreal Sweden, Doctor's Dissertation. Swedish University of Agricultural Sciences, Department of Silviculture. Umeå Sweden.

Author abstract. Volume increment and ingrowth are important aspects of stand development and regeneration dynamics for determining the effectiveness of uneven-aged silvicultural systems. The main objectives of this thesis were to establish the influence of standing volume on volume increment after different kinds of harvest regimes, the influence of overstorey density on height growth of advance regeneration, and the influence of bilberry (Vaccinium myrtillus L.) on spruce regeneration in managed uneven-aged Norway spruce (Picea abies (L.) Karst.) forests in boreal Sweden. Model simulations with 5-year growth iterations and three harvest regimes of diameter-limit, single-tree selection, and schematic harvests were used to investigate the influence of standing volume on volume increment. Additionally, field experiments at two sites, re-inventoried ten years after treatments that had a 3×2 factorial design of three thinning intensities (30, 60, 85% of pre-harvest standing volume) and two types of thinning (harvested larger or smaller trees), were used. The influence of overstorey density on height growth was established using one of the sites that measured height increments of seedlings, saplings, and small trees in the plots. A field investigation was carried out to establish the influence of bilberry on spruce saplings, which cut bilberry stems in 1 m2 circle plots around treated saplings and their height growth compared to the control saplings with uncut bilberry stems.

Volume increment increased with increasing standing volume, culminated, and eventually declined. The highest volume increment was found for diameter-limit harvests followed by single-tree selection and schematic harvests. For harvesting a residual stand to 50 m3ha-1, the schematic harvest showed increment losses equaling 25 years of growth. For the field experiments at both sites, standing volume was correlated significantly positively ($p<0.05$) with volume increment. Only for the more productive site, standing volume was correlated significantly negatively ($p<0.05$) with ingrowth. The height increments for all spruce advance regeneration were better correlated with canopy openness than with basal area or standing volume. Treated saplings decreased in height increment compared to the control during the first and second year after cutting bilberry.

In conclusion, volume increment increased with increasing standing volume and harvesting mostly the larger trees in a residual stand with large number of stems and large number of small trees yields high volume increments. At both sites the ingrowth of spruce regeneration was low, but higher than mortality and the number of trees removed, and thus it was sufficient to replace the harvested trees. The cutting of bilberry reduced the height growth of spruce regeneration.

◆ **Conway, A.J. and R.K. Danby. 2014.** Recent advance of forest–grassland ecotones in southwestern Yukon. CJFR 44(5): 509-520, 10.1139/cjfr-2013-0429.

Author abstract. We investigated recent ecotone dynamics in the forest-grassland mosaics of southwestern Yukon. Our objectives were to determine (*i*) if forests are encroaching into grasslands, (*ii*) if rate and extent of encroachment varies by region or with topographic setting, and (*iii*) if encroachment is related to climate change and variability. Dendroecological techniques were used to obtain dates of establishment for 1847 trees (trembling aspen (*Populus tremuloides* Michx.) and white spruce (*Picea glauca* (Moench) Voss)) sampled from 28 sites divided between two different regions and three topographic settings. Generalized linear modeling was used to identify relationships between climate and tree establishment. Results show that encroachment of forest, particularly aspen trees, into grasslands has been nearly ubiquitous on flat terrain and on south-facing slopes in both regions over the last 60–80 years. In contrast, spruce-dominated ecotones on north-facing slopes experienced little change. Aspen establishment was positively associated with spring temperatures and precipitation, although evidence suggests that other factors such as soil moisture interact with climate to mediate the timing and rate of tree encroachment. These results indicate that transformation of grasslands to aspen-dominated forest is an additional, but previously unexplored, element of the widespread ecosystem changes currently being experienced in northwestern North America.

◆ **Drake, G.L. 1965.** Birch-spruce forests of the upper Cook Inlet region of Alaska . USDA Forest Service, U.S. G.P.O. 11 pp.

Author abstract. Twenty years ago the name Alaska brought to the mind a vast treasure house of gold; today we think of Alaska as one of the coming centers of the pulp industry, and twenty years hence may see southwestern and central Alaska the home of many wood-working plants, utilizing the Alaska birch. The recent completion of the government railroad from Seward to Fairbanks, which passes through the birch-spruce forest for the major part of its distance, has made these forests accessible. The birch-spruce forests lie on two great watersheds—the Susitna, which drains west into Cook Inlet, and the Yukon which drains north into Bering Sea. This article treats of the forests of the Upper Cook Inlet country as they, due to their greater accessibility, will be exploited before the vast forests of the Yukon country. During the summer of 1916 the writer while on timber sale administrative work along the government railroad in the Cook Inlet region had an opportunity to study these birch-spruce forests. Only a portion of the area was traversed in the field and the number of trees which form the basis of the tables was limited, but it is felt this information will be of interest to the profession as it deals with a region and species of which little is known.

◆ **Feng, Zhili, Stadt, Kenneth J., and Lieffers, Victor J. 2006.** Linking juvenile white spruce density, dispersion, stocking, and mortality to future yield. Canadian Journal of Forest Research, 36: 3173–3182.

Author abstract. We examined methods of linking density, dispersion, and stocking information from juvenile regeneration surveys with mortality estimates to predict future yield of white spruce (Picea glauca (Moench) Voss) in boreal mixedwoods. The study focused on data from 709 stands (7–150 years) and defined a stocked plot (10 m2) as having one or more acceptable trees. In juvenile surveys, ingress of natural spruce overwhelmed the regular planting pattern, creating clumped dispersion patterns, as indicated by the Morisita index. A function was developed to describe the relationship between stocking, density, and dispersion. In mature, permanent sample plots, only 30%–40% stocking of 10 m2 plots (700 stems·ha–1) was needed to achieve full yields. Mortality rates for planted spruce varied from 0.1% to 0.8% per year for juvenile stands and from 1.7% to 3.3% per year for mature stands. For rotation-length predictions in Alberta, 0.7% per year is likely a mean mortality loss. These findings were combined to generate stocking versus time curves at a range of mortality rates. The tallest spruce measured in each juvenile survey plot had the same mortality rate regardless of absolute size, and spruce mortality was reduced when associated with aspen. These findings call into question minimum height requirements and free-to-grow criteria in regeneration standards.

◆ **Gärtner, S. M., V. J. Lieffers, and S. E. Macdonald. 2011**. Ecology and management of natural regeneration of white spruce in the boreal forest. Environmental Reviews 19:461-478.

Author abstract. Most forest managers view natural regeneration of Picea glauca (white spruce) after forest harvesting to be unreliable; in this paper the Authors dispute this idea by describing the factors influencing natural regeneration of spruce, i.e., seed production, dispersal, germination and seedling establishment and discussing the opportunities for encouragement of natural regeneration after logging. Seed supply is greatest from trees with large crowns, that are positioned in the upper canopy and seeding is greatest in mast years. Maintaining at least five mature white spruce trees per hectare within cut areas or dense stands of spruce on edges of cutovers ensures pollination success as well as even seed distribution. The most suitable seedbeds for white spruce germination are mineral soil, mineral soil with a thin organic layer, or large downed rotten logs. Mineral soil seedbeds are available for a short time after fire or other disturbances, while downed wood becomes available over time; this results in recruitment immediately after disturbance or several decades later. To increase the availability of suitable seedbeds the soil can be scarified during or after harvest and nurse logs should be left; on wet sites mounding should be considered. Partial canopy cover can protect seedlings from climate extremes while limiting competing vegetation. Using natural regeneration, a range of stocking outcomes can be expected — from no stocking to overstocking of spruce. Such variation in the amount of spruce versus broadleaf species, however, is consistent with the range of variation in forest composition found naturally in the boreal mixedwood region.

◆ **Greene, D. F., Zasada, J. C., Sirois, L., Kneeshaw, D., Morin, H., Charron, I., and Simard, M. J. 1999.** A review of the regeneration dynamics of North American boreal forest tree species. Canadian Journal of Forest Research, 29: 824-839.

Author abstract. In this review, we focus on the biotic parameters that are crucial to an understanding of the recruitment dynamics of North American boreal tree species following natural (fire, budworm infestation, windthrow) or human induced (clearcut, partial cut) disturbances. The parameters we emphasize are (i) the production of seeds and asexual stems (both of which, we argue, are a function of basal area density), (ii) the dispersal of seeds by wind (or the dispersion of asexual stems) as a function of distance from source, (iii) dormant seed bank capacity, (iv) organic layer depth as a determinant of germinant mortality and asexual bud response, and (v) shade tolerance as a partial arbiter of the density of advanced regeneration. Having identified the gaps in our knowledge, we conclude by suggesting a short term research agenda whose completion would lead to the parameterized functions that would constitute the recruitment subroutine in a landscape-scale forest dynamics simulator.

◆ **Harvey, B.D., Leduc, A., Gauthier, S., Bergeron, Y., 2002.** Stand-landscape integration in natural disturbance-based management of the southern boreal forest. For. Ecol. Manage. 155, 369-385. Johnstone, J., Chapin, F., 2006. Effects of soil burn severity on post-fire tree recruitment in boreal forest. Ecosystems 9, 14-31.

Author abstract. Forest ecosystem management, based partly on a greater understanding of natural disturbance regimes, has many variations but is generally considered the most promising approach to accommodating biodiversity concerns in managed forested regions. Using the Lake Duparquet Forest in the southeastern Canadian boreal forest as an example, we demonstrate an approach that attempts to integrate forest and stand-level scales in biodiversity maintenance. The concept of cohorts is used to integrate stand age, composition and structure into broad successional or stand development phases. Mean forest age (MFA), because it partly incorporates historic variability of the regional fire cycle, is used as a target fire cycle. At the landscape level, forest composition and cohort objectives are derived from regional natural disturbance history, ecosystem classification, stand dynamics and a negative exponential age distribution based on a 140 year fire cycle. The resulting multi-cohort structure provides a framework for maintaining the landscape in a semi-natural age structure and composition. At the stand level, the approach relies on diversifying interventions, using both even-aged and uneven-aged silviculture to reflect natural stand dynamics, control the passage ("fluxes") between forest types of different cohorts and maintain forest-level objectives. Partial and selective harvesting is intended to create the structural and compositional characteristics of mid- to late-successional forest types and, as such, offers an alternative to increasing rotation lengths to maintain ecosystem diversity associated with over-mature and old-growth forests. The approach does not however supplant the necessity for complementary strategies for maintaining biodiversity such as (lie creation of reserves to protect rare, old or simply natural ecosystems. The emphasis on maintaining the cohort structure and forest type diversity contrasts significantly with current even-aged management in the Canadian boreal forest and has implications for stand-level interventions, notably in necessitating a greater diversification of silvicultural practices including more uneven-aged harvesting regimes. The approach also presents a number of operational challenges and potentially higher risks associated with multiply stand entries, partial cutting and longer intervals between final harvests. There is a need for translating the conceptual model into a more quantitative silvicultural framework. Silvicultural trials have been established to evaluate stand-level responses to treatments and operational aspects of the approach.

◆ **Hynynen, J., P. Niemistö, A. Viherä-Aarnio, A. Brunner, S. Hein, and P. Velling. 2010.** Silviculture of birch (Betula pendula Roth and Betula pubescens Ehrh.) in northern Europe. Forestry 83:103-119.

Author abstract. In Europe, two commercially important treelike birch species occur naturally: silver birch (Betula pendula Roth) and downy birch (Betula pubescens Ehrh.). Both species have a wide natural distribution area on the Eurasian continent, ranging from the Atlantic to eastern Siberia. Although birches occur throughout almost the whole of Europe, the most abundant birch resources are in the temperate and boreal forests of Northern Europe. In the Baltic and Nordic countries, the proportion of birch out of the total volume of the growing stock varies between 11 and 28 per cent. In Northern Europe, birch is commercially the most important broadleaved tree species.

Birches are light-demanding early successional pioneer species, which grow both in mixed stands and in pure stands. This article provides an overview of the most important ecological characteristics and typical growth and yield patterns of birch, based on European scientific literature. Growth and yield research on birch has been relatively active in Northern Europe, where numerous growth and yield models have been developed during the last decades. In this paper, a list of published scientific articles on growth modelling is provided and is grouped according to the different types of model.

When growing in forest stands, birches have a relatively straight slender stem form. The current practices and silvicultural recommendations, based on research directed at high-quality timber production in silver birch stands, are reviewed. Although the emphasis is on even-aged pure silver birch stands, the management of mixed stands as well as the silviculture of downy birch and curly birch are also briefly discussed.

◆ **Juday, Glenn P. 2013.** Monitoring Hectare-Scale Forest Reference Stands At Bonanza Creek Experimental Forest LTER. In: Camp, A.E.; Irland, L.C.; Carroll, C.J.W. (eds.) Long-term Silvicultural & Ecological Studies: Results for Science and Management, Volume 2.

Author abstract. A long-term forest ecological monitoring project has been underway on the Bonanza Creek Experimental Forest (BCEF) in central Alaska since 1986.

◆ **Kabzems, R.D., G. Harper, and P. Fielder. 2011.** Western Journal of Applied Forestry, Volume 26, Number 2, April 2011, pp. 82-90(9).

Author abstract. Managing boreal mixed stands of trembling aspen (Populus tremuloides Michx.) and white spruce (Picea glauca [Moench] Voss) is more likely to sustain a diversity of values and has the potential to increase productivity at both the site and landscape levels compared with pure broadleaf or conifer management. In this study, we examine growth of white spruce and aspen after 11 growing seasons over a range of aspen densities created by spot and broadcast treatment of broadleaves using manual and chemical means, aspen spacing, and an untreated control. Results indicate that survival and growth of both spruce and aspen were similar across the range of treatments. Spruce groundline diameter was greater, and height to groundline diameter ratio was lower, for the treatments in which aspen was chemically controlled or uniformly spaced compared with the control. Light measurements at the individual tree level suggested that increased light availability improved white spruce diameter growth. Spruce height growth did not vary by treatment. The status of these experimental mixedwoods was compared with current conifer and mixedwood regeneration evaluations, as well as the preharvest composition of the original stand. After 11 growing seasons, growth of aspen and white spruce indicated that opportunities exist to further modify aspen density to enhance treatment longevity and effectiveness to produce a greater range of boreal mixedwood stand types.

◆ **Kneeshaw, D. and S. Gauthier. 2003**. Old growth in the boreal forest: A dynamic perspective at the stand and landscape level. Environmental Reviews 11:S99-S114.

Author abstract. Old-growth forests have been identified as a potentially important stage of stand development for maintaining biodiversity in the landscape, yet they have also been targeted by the forest industry in their drive to regulate the forest. We will attempt to propose a definition of old growth, applicable throughout the North American boreal forest, that takes into account the dynamic nature of forest development and that could be useful for management and conservation purposes. We define the start of the old-growth stage as occurring when the initial post-disturbance cohort begins dying off, concurrent with understorey stem recruitment into the canopy. We propose that species longevity and the regional fire cycle can be used to assess the extent of this phase in different regions. Using published data on fire history, we show that the amount of old growth expected to occur in western and central Canada is less than in eastern Canada, where most stands (in area) escape fire for periods longer than that necessary to incur substantial mortality of the initial cohort. At the stand level, we show that the old-growth stage is characterized by small-scale disturbances that engender gap dynamics. Until recently, this process had not been studied in the boreal forest. The old-growth index we present suggests that the relationship between time since the last major disturbance and old growth status varies most in areas that have not been disturbed for long periods. Both management and conservation strategies have to take into account that old-growth forests are dynamic. To be effective, reserves should contain all stages of development and should be sufficiently large to encompass rare but large disturbances. The abundance of old growth in many boreal regions of North America also suggests that forest management strategies other than even-aged, fully regulated systems have to be developed.

◆ **Kneeshaw, D.D., Bergeron, Y., 1998**. Canopy gap characteristics and tree replacement in the southeastern boreal forest. Ecology 79, 783-794.

Author abstract. This study identifies patterns in the gap disturbance regime along a successional gradient in the southern boreal forest and uses this information to investigate canopy composition changes. Gaps were characterized in hardwood, mixed-forest, and conifer stands surrounding Lake Duparquet in northwestern Quebec. From 39 to 80 gaps were evaluated along transects established in each of these stands. The abundance of gap makers and gap fillers and total regeneration was evaluated by species, as well as the size of each gap encountered along the transects. The percentage of the forest in canopy gap was calculated directly from the proportion of the transect in gap and by using gap area and line intercept techniques. Changes in composition were evaluated from gap-maker and gap filler distributions and by using transition matrices based on species mortality and regeneration in canopy gaps. The percentage of the forest in canopy gap ranges from 7.1% in a 50-yr old forest dominated primarily by aspen to 40.4% in a 234-yr-old fir-dominated forest. Gap events are due to individual or small-group tree mortality in the early successional forest but become species-specific events controlled by spruce budworm outbreaks in the later stages of succession. Due to the high latitude, direct light only reaches the forest floor in the very largest gaps of the conifer-dominated stands. However, these gaps form slowly as budworm caused mortality occurs over a number of years, whereas in aspen-dominated stands gaps are formed quickly by the snapping of tree stems. Balsam fir is the most abundant gap filling species; however, its abundance is negatively correlated to gap size in all stand types. Markovian transition matrices suggest that in the young aspen-dominated forests small gaps lead to species replacement by more shade-tolerant conifers but that in the oldest forests the larger gaps will result in maintenance of the intolerant species and an increase in the abundance of cedar.

◆ **Kneeshaw, D.D., Leduc, A., Drapeau, P., Gauthier, S., Pare, D., Carignan, R., Doucet, R., Bouthillier, L., Messier, C., 2000.** Development of integrated ecological standards of sustainable forest management at an operational scale. For. Chron. 76, 481-493.

Author abstract. Within Canada, and internationally, an increasing demand that forests be managed to maintain all resources has led to the development of criteria and indicators of sustainable forest management. There is, however, a lack of understanding, at an operational scale, how to evaluate and compare forest management activities to ensure the sustainability of all resources. For example, nationally, many of the existing indicators are too broad to be used directly at a local scale of forest management; provincially, regulations are often too prescriptive and rigid to allow for adaptive management; and forest certification programs, often based largely on public or stakeholder opinion instead of scientific understanding, may be too local in nature to permit a comparison of operations across a biome. At an operational scale indicators must be relevant to forest activities and ecologically integrated. In order to aid decision-makers in the adaptive management necessary for sustainable forest management, two types of indicators are identified: those that are prescriptive to aid in planning forest management and those that are evaluative to be used in monitoring and suggesting improvements. An integrated approach to developing standards based on an ecosystem management paradigm is outlined for the boreal forest where the variability inherent in natural systems is used to define the limits within which forest management is ecologically sustainable. Sustainability thresholds are thus defined by ecosystem response after natural disturbances. For this exercise, standards are proposed for biodiversity, forest productivity via regeneration, soil conservation and aquatic resources. For each of these standards, planning indicators are developed for managing forest conditions while forest values are evaluated by environmental indicators, thus leading to a continuous cycle of improvement. Approaches to developing critical thresholds and corresponding prescriptions are also outlined. In all cases, the scale of evaluation is clearly related to the landscape (or FMU) level while the stand level is used for measurement purposes. In this view the forest should be managed as a whole even though forest interventions are usually undertaken at the stand level.

◆ **Kurkowski, T.A., D.H. Mann, T. S. Rupp, D. L. Verbyla. 2008**. Relative importance of different secondary successional pathways in an Alaskan boreal forest. CJFR , 2008, 38(7): 1911-1923, 10.1139/X08-039

Author abstract. Postfire succession in the Alaskan boreal forest follows several different pathways, the most common being self-replacement and species-dominance relay. In self-replacement, canopy-dominant tree species replace themselves as the postfire dominants. It implies a relatively unchanging forest composition through time maintained by trees segregated within their respective, ecophysiological niches on an environmentally complex landscape. In contrast, species-dominance relay involves the simultaneous, postfire establishment of multiple tree species, followed by later shifts in canopy dominance. It implies that stand compositions vary with time since last fire. The relative frequencies of these and other successional pathways are poorly understood, despite their importance in determining the species mosaic of the present forest and their varying, potential responses to climate changes. Here we assess the relative frequencies of different successional pathways by modeling the relationship between stand type, solar insolation, and altitude; by describing how stand age relates to species composition; and by inferring successional trajectories from stand understories. Results suggest that >70% of the study forest is the product of self-replacement, and tree distributions are controlled mainly by the spatial distribution of solar insolation and altitude, not by time since last fire. As climate warms over the coming decades, deciduous trees will invade cold sites formerly dominated by black spruce, and increased fire frequency will make species-dominance relay even rarer.

◆ **Lamontagne, J. M. and S. Boutin. 2007.** Local-scale synchrony and variability in mast seed production patterns of *Picea glauca*. Journal of Ecology, 95: 991–1000. doi: 10.1111/j.1365-2745.2007.01266.x

Author summary. Mast seeding is the synchronous and highly variable production of seed by a population of plants. Mast seeding results from the behaviour of individuals; however, little is known about the synchrony of individuals at local scales. We address two primary questions at a within-population (17–36 ha study plots) and individual level: (i) How variable is seed production between and within years? (ii) How synchronized is seed production between individuals? We monitored annual cone production of 356 *Picea glauca* (white spruce) from 1990 to 2005 within four plots spanning a total distance of 5.3 km in the Yukon Territory, Canada. Spearman correlations (r_s) were conducted to test for synchrony. Overall, the trees were moderately synchronous (mean r_s (± SE) of 0.52 ± 0.14), and synchrony was statistically detectable ($r_s > 0$) over all distances. Individuals < 75 m apart were highly synchronous (0.64 ± 0.18), and correlations dropped to 0.33 ± 0.07 for trees > 3 km apart. There was considerable variation in cone production patterns among pairs of individuals. The number of mast years per plot varied from one to three. During a mast year, many individuals within plots produced large cone crops, with more variability between individuals in low mean cone years. Individual trees had dominant endogenous cycles varying from none to 1–5 years. Forty-four per cent of trees had no significant lag, 23% a negative 1-year lag, and 20% a positive 3-year lag. Basal area did not influence lags, but trees with higher mean cone production throughout the study were more likely to have a 3-year lag compared with no lag. The scale of highest synchrony coincided with the scale at which the dominant seed predator in the area, the territorial red squirrel (*Tamiasciurus hudsonicus*), operates. This may be the scale at which selection for synchrony occurs. Based on high synchrony locally, high synchrony within a mast year, and multiple lags in cone production by individuals, both available resources and strong weather cues appear to play roles in the observed patterns.

◆ **Lieffers, V.J., K.J. Stadt, and S. Navratil. 1996.** Age structure and growth of understory white spruce under aspen. Canadian Journal of Forest Research, 26: 1002-1007.

Author abstract. Juvenile white spruce (Picea glauca (Moench) Voss) under an aspen (Populus tremuloides Michx.) overstory were studied in nine boreal mixedwood stands in west-central Alberta. In each stand, 50 understory white spruce were cut for stem analysis at ground level, 30, 70, 130 cm, and every 100 cm to tree height. In four stands, recruitment of these understory spruce occurred immediately after the disturbance, while in others the recruitment was delayed several decades. The period of recruitment was as short as 15–20 years or continued for decades, producing an uneven-aged understory. Trees initiated on rotten logs had a slightly lower initial annual diameter increment but did not differ in height growth compared with those initiated on normal forest floor. The annual height increment increased as the trees grew in height, presumably as they overtopped successive layers of shading vegetation. When seedlings were less than 30 cm tall they grew less than 10 cm per year, but attained growth rates of 30 cm per year or more when they were taller than 230 cm. Height growth rates for these understory trees were comparable to reported growth rates of white spruce of similar size and age from clearcut area.

◆ **Lloyd, A.H., C.L. Fastie, and H. Eisen. 2007.** Fire and substrate interact to control the northern range limit of black spruce (*Picea mariana*) in Alaska. Can. J. For. Res. 37(12): 2480-2493, 10.1139/X07-092

Author abstract. Black spruce (Picea mariana (Mill.) BSP) is a common treeline species in eastern Canada but rare at treeline in Alaska. We investigated fire and substrate effects on black spruce populations at six sites along a 74 km transect in the Brooks Range, Alaska. Our southern sites, on a surface deglaciated >50 000 years ago, had significantly more acidic soils, more black spruce, and higher seed viability than our northern sites, which were deglaciated approximately 13 000 years ago. Despite similar fire history at five of our six sites, postfire recruitment dynamics varied with surface age. Sexual reproduction was vigorous in both postfire and nonfire years in populations on the older surface. On the younger surface, vigorous sexual reproduction was restricted to postfire decades and clonal reproduction by branch layering predominated in nonfire years. At the northernmost site, which was unburned, black spruce reproduced almost exclusively by layering. The species' northern range limit thus reflects an interaction between fire and substrate: on recently deglaciated surfaces, sexual reproduction is restricted to postfire years. This substrate-induced dependence on fire may restrict the range of black spruce to sites that burn sufficiently often to allow occasional sexual reproduction.

◆ **Lloyd, A.H., A.E. Wilson, C.L. Fastie, and R.M. Landis. 2005.** Population dynamics of black spruce and white spruce near the arctic tree line in the southern Brooks Range, Alaska Can. J. For. Res. 35(9): 2073-2081, 10.1139/x05-119

Author abstract. Black spruce (*Picea mariana* (Mill.) BSP) is the dominant species in interior Alaska but it is largely absent from the arctic tree line. To evaluate the importance of climate and fire as controls over the species distribution, we reconstructed stand history at three sites near its northern limit in Alaska, where it grows with white spruce (*Picea glauca* (Moench) Voss). We developed a matrix model to explore black spruce population dynamics and response to varying fire intervals. All sites burned in the early 1900s. High recruitment of black spruce occurred for <30 years following the fire, but most current black spruce recruitment is clonal and seed viability is low. White spruce recruitment has been consistently high since the fire, and the majority of seedlings in the stands are white spruce. Despite low recruitment, the matrix model suggests that black spruce populations are nearly stable, largely because of low adult mortality rates. Although black spruce recruitment is stimulated by fire, the model indicates that fire intervals <350 years would destabilize the population, primarily because of slow growth and low seed production. Population dynamics of black spruce at its northern limit in Alaska thus appear to reflect an interaction between fire, which determines the temporal pattern of tree recruitment, and climate, which limits tree growth and, presumably, viable seed production.

◆ **Long, J.N. and K. Mock. 2012.** Changing perspectives on regeneration ecology and genetic diversity in western quaking aspen: implications for silviculture. CJFR 42(12): 2011-2021, 10.1139/x2012-143.

Author abstract. A conventional view of regeneration ecology of quaking aspen (*Populus tremuloides* Michx.) in western North American holds that reproduction is strictly vegetative and, except on some marginal sites, only successful following high-severity disturbance. This view has strongly influenced silvicultural treatment of western aspen and has led to low expectations concerning genetic diversity of stands and landscapes. However, recent discoveries are fundamentally altering our understanding of western aspen regeneration ecology and genetics. For example, there are clearly multiple pathways of aspen regeneration and stand development. Research on a variety of fronts indicates that seedling establishment is common enough to be ecologically important and that genetic diversity is substantially greater than previously thought. We review conventional understanding of western aspen and put this into the context of silvicultural practice. We then review recent developments in aspen research and assess the silvicultural implications of these insights.

◆ **Messier, C., Doucet, R., Ruel, J.C., Claveau, Y., Kelly, C., Lechowicz, M.J., 1999.** Functional ecology of advance regeneration in relation to light in boreal forests. Can. J. For. Res.-Rev. Can. Rech. For. 29, 812-823.

Author abstract. This paper reviews aspects of the functional ecology of naturally established tree seedlings in the boreal forests of North America with an emphasis on the relationship between light availability and the growth and survival of shade tolerant conifers up to pole size. Shade tolerant conifer species such as firs and spruces tend to have a lower specific leaf mass, photosynthetic rate at saturation, live crown ratio, STAR (shoot silhouette area to total needle surface area ratio), and root to shoot ratio than the shade intolerant pines. The inability of intolerant species such as the pines and aspen to survive in shade appears to be mainly the result of characteristics at the. shoot, crown, and whole-tree levels and not at the leaf level. Although firs and spruces frequently coexist in shaded understories, they do not have identical growth patterns and crown architectures. We propose a simple framework based on the maximum height that different tree species can sustain in shade, which may help managers determine the timing of partial or complete harvests. Consideration of these functional aspects of regeneration is important to the understanding of boreal forest dynamics and can be useful to forest managers seeking to develop or assess novel silvicultural systems.

◆ **Metslaid, M., Jogiste, K., Nikinmaa, E., Moser, W.K., Porcar-Castell, A., 2007.** Tree variables related to growth response and acclimation of advance regeneration of Norway spruce and other coniferous species after release. Forest Ecology and Management 250:56-63.

Author abstract. Modern forestry has been evolving towards multiple-use of forests and maintenance of biodiversity. Interest in integrating natural forest dynamics into management planning and silvicultural practices has increased as a result of concerns related to biodiversity values and maintaining ecological functions in managed forests. Taking advantage of naturally formed advance regeneration to create a new forest is one way of emulating natural forest dynamics, especially in spruce forests. However, efficient use of advance regeneration requires knowledge about factors influencing their performance. Light is important for growth and for crown, shoot and needle morphology of Norway spruce (Picea abies). Crown morphology varies from a conical and deep crown form in relatively high-light environments to the typical "umbrella" form in the understory shade. Shoots and needles developed in shade are flatter and experience less self-shading than those developed in more light. Needle orientation is horizontal in shade and more vertically inclined in light. The number of nodal and internodal branches increases with increasing light. Tree shoot characteristics are strongly correlated and highly dependent on growing conditions, particularly light. There is a correlation between shoot and needle mass and other shoot variables of current and consecutive year's growth. The strongest correlations are between length of the shoot and needle mass of the shoot, and the length of the shoot and number of needles on the shoot. Needle length was not as sensitive to the light environment. However, needle width and thickness increased with canopy openness. This paper presents a review of selected literature on the relationships between different tree variables and ecophysiological factors that influence the response and acclimation of Norway spruce advance regeneration to release. The results indicate that crown, shoot and needle characteristics could reflect the acclimation to light conditions and indicate the performance of advance regeneration after release.

◆ **Roessler, J.S. 1997.** Disturbance history in the Tanana River basin of Alaska: Management implications. Unpubl. M.S. Thesis, Univ. Alaska, Fairbanks, 220 p.

Author abstract. The forests of the Tanana River Basin in Interior Alaska have a history of disturbance. Four issues reflecting forest disturbance. important to include in current management strategies for these lands were researched: (1) disturbance history of the Tanana Valley; (2) Alaska Interagency Fire Management Plan: a case study; (3) prescribed natural fire in Alaska: possibilities and complexities; and (4) past use of prescribed fire in white spruce: a summary with particular reference to Alaska. Through researching historical archives, conducting field site visits, interviewing land and fire managers and reviewing current planning documents. I reached four major conclusions: (1) there is lack of use of historical facts regarding human-induced changes on the landscapes; (2) past involvement of public stake-holders in fire planning in Alaska was inadequate; (3) the Alaska Interagency Fire Management Plans need to identify scientific prescription parameters which address specific land management objectives; and (4) management-ignited prescribed fire must become a more common prescription after harvesting of white spruce.

◆ **Rossi, S., Tremblay, M.J., Morin, H., Savard, G., 2009**. Growth and productivity of black spruce in even- and uneven-aged stands at the limit of the closed boreal forest. For. Ecol. Manage. 258, 2153-2161.

Author abstract. The increasing commercial interest and advancing exploitation of new remote territories of the boreal forest require deeper knowledge of the productivity of these ecosystems. Canadian boreal forests are commonly assumed to be evenly aged, but recent studies show that frequent small-scale disturbances can lead to uneven-aged class distributions. However, how age distribution affects tree growth and stand productivity at high latitudes remains an unanswered question. Dynamics of tree growth in even- and uneven-aged stands at the limit of the closed black spruce (Picea mariana) forest in Quebec (Canada) were assessed on 18 plots with ages ranging from 77 to 340 years. Height, diameter and age of all trees were measured Stem analysis was performed on the 10 dominant trees of each plot by measuring tree-ring widths on discs collected each meter from the stem, and the growth dynamics in height, diameter and volume were estimated according to tree age Although growth followed a sigmoid pattern with similar shapes and asymptotes in even- and uneven-aged stands, trees in the latter showed curves more flattened and with increases delayed in time. Growth rates in even-aged plots were at least twice those of uneven-aged plots The vigorous growth rates occurred earlier in trees of even-aged plots with a culmination of the mean annual increment in height, diameter and volume estimated at 40-80 years, 90-110 years earlier than in uneven-aged plots. Stand volume ranged between 30 and 238 m(3) ha(-1) with 75% of stands showing values lower than 120 m(3) ha(-1) and higher volumes Occurring at greater dominant heights and stand densities. Results demonstrated the different growth dynamics of black spruce in single- and multi-cohort stands and suggested the need for information on the stand structure when estimating the effective or potential growth performance for forest management of this species.

◆ **Shaw, J.D. 1994.** Growth patterns of balsam poplar and black cottonwood in interior and southcentral Alaska . Unpubl. M.S. Thesis. Univ. of Alaska Fairbanks. 305 pp.

Need abstract ***checking with CR***

◆ **Taylor, A.R., Chen, H.Y.H., 2011.** Multiple successional pathways of boreal forest stands in central Canada. Ecography 34, 208-219.

Author abstract. Predicting forest composition change through time is a key challenge in forest management. While multiple successional pathways are theorized for boreal forests, empirical evidence is lacking, largely because succession has been inferred from chronosequence and dendrochronological methods. We tested the hypotheses that stands of compositionally similar overstory may follow multiple successional pathways depending on time since last stand-replacing fire (TSF), edaphic conditions, and presence of intermediate disturbances. We used repeated measurements from combining sequential aerial photography and ground surveys for 361 boreal stands in central Canada. Stands were measured in 8-15 yr intervals over a similar to 60 yr period, covering a wide range of initial stand conditions. Multinomial logistic regression was used to analyze stand type transitions. With increasing TSF, stands dominated by shade-intolerant Pinus banksiana, Populus sp., and Betula papyrifera demonstrated multiple pathways to stands dominated by shade-tolerant Picea sp., Abies balsamea, and Thuja occidentalis. Their pathways seemed largely explained by neighborhood effects. Succession of stands dominated by shade-tolerant species, with an exception of stands dominated by Picea sp., was not related to TSF, but rather dependent on edaphic conditions and presence of intermediate disturbances. Varying edaphic conditions caused divergent pathways with resource limited sites being dominated by nutrient-poor tolerant species, and richer sites permitting invasion of early successional species and promoting species mixtures during succession. Intermediate disturbances promoted deciduous persistence and species diversity in A. balsamea and mixed-conifer stands, but no evidence was detected to support "disturbance accelerated succession". Our results demonstrate that in the prolonged absence of stand-replacing disturbance boreal forest stands undergo multiple succession pathways. These pathways are regulated by neighborhood effects, resource availability, and presence of intermediate disturbance, but the relative importance of these regulators depends on initial stand type. The observed divergence of successional pathways supports the resource-ratio hypothesis of plant succession.

◆ **Taylor, R. F. 1934.** A preliminary study of natural reproduction and timber growth of the Kenai Division, Chugach National Forest . U.S. Dept. of Agriculture, Forest Service, Chugach National Forest; Washington, D.C. : U.S. G.P.O. Special Studies – Kenai Division. 10 pp.

Compiler abstract. This 1934 paper describes vegetation on the Kenai Peninsula, primarily in the coastal forest. There is a short description of the interior forest type.

◆ **Vogt, S.L. 2002.** A characterization of mixed forest stands in the Tanana Valley, Alaska. Unpubl. Thesis. Univ. of Alaska Fairbanks, Agric. and For. Exp. Station. 153 pp.

Author abstract. The objective of this thesis is to define the composition, age structure, volume ranges, and community types present in the Tanana Valley mixed stands. Sixty-six permanent sample plots were established in 22 forest stands located throughout the Valley. Plots were at least 100 feet from a road. Total height, crown height, diameter breast height were measured and health and vigor were assessed for 5,415 trees. Five tree species and 57 herb and shrub species were found. White spruce, birch, and aspen numbers are generally less in mixed stands than predicted for pure stands. Stand density index values, a method of assessing species' use of growing space, ranged from 61 to 422 stems per acre with a mean of 269. Existing individual tree volume tables need revision to avoid negative values for small trees. Existing site index curves for pure stands of Interior species are inadequate for comparing to mixed stands.

◆ **Wilmking, M. 2003.** The treeline ecotone in interior Alaska : from theory to planning and the ecology in between. Unpubl.. PhD thesis. Univ. of Alaska Fairbanks. 130 pp.

Author abstract. Treelines have been the focus of intense research for nearly a hundred years, also because they represent one of the most visible boundaries between two ecological systems. In recent years however, treelines have been studied, because changes in forest ecosystems due to global change, e.g. treeline movement, are expected to manifest first in these areas. This dissertation focuses on the elevational and latitudinal treelines bordering the boreal forest of interior Alaska. After development of a conceptional model of ecotones as three-dimensional spaces between ecosystems, we offer a historical perspective on treeline research and its broader impact in the Brooks Range, Alaska. Dendrochronological analysis of >1500 white spruce (Picea glauca) at 13 treeline sites in Alaska revealed both positive and negative growth responses to climate warming, challenging the widespread assumption that northern treeline trees grow better with warming climate. Hot Julys decreased growth of 40% of white spruce at treeline in Alaska, whereas warm springs enhanced growth of others. Growth increases and decreases appear at temperature thresholds, which have occurred more frequently in the late 20th century. Based on these relationships between tree-growth and climate as well as using landscape characteristics, we modeled future tree-growth and distribution in two National Parks in Alaska and extrapolated the results into the 21st century using climate scenarios from five General Circulation Models. In Gates of the Arctic National Park our results indicate enhanced growth at low elevation, whereas other areas will see changes in forest structure (dieback of tree-islands, infilling of existing stands). In Denali National Park, our results indicate possible dieback of white spruce at low elevations and treeline advance and infilling at high elevations. This will affect the road corridor with a forest increase of about 50% along the road, which will decrease the possibility for wildlife viewing. Surprisingly, aspect did not affect tree growth - climate relationships. Without accounting for opposite growth responses under warming conditions, temperature thresholds, as well as meso-scale changes in forest distribution, climate reconstructions based on ring-width will miscalibrate past climate, and biogeochemical and dynamic vegetation models will overestimate carbon uptake and treeline advance under future warming scenarios.

◆ **Winslow, S.E. 2008.** Tree growth history, climate sensitivity, and growth potential of black and white spruce along the middle Kuskokwim River, Alaska . Unpubl. M.S. Thesis. Univ. of Alaska Fairbanks. 68 pp.

Author abstract. People living in the Kuskokwim River Basin often rely on wood to heat their homes and are considering wood-fueled energy generation. To help inform community decisions we examined the growth history, climate sensitivity and growth potential of local tree species. We compared ring-width growth of 188 white spruce (Picea glauca (Moench) Voss) and 77 black spruce and black spruce (Picea mariana (Mill.)B.S.P.) trees sampled along 370 km of the Kuskokwim River, Alaska to mean monthly temperatures (MMT) and total monthly precipitation (TMP) at McGrath. White spruce trees were either significantly negatively correlated (r = -0.62) with MMT of August and June (-2) (two years prior to ring formation) or positively correlated (r=0.60) with MMT of April (-2) and November (-2). Black spruce trees were either negatively correlated (r = -0.64) with a warmth-dryness index composed of August and June (-1) MMT minus TMP of August and June (-2) or positively correlated (r = 0.60) with April (-1) and June (-1) MMTs. Negative growth responders predominate in eastern (warmer and dryer) locations while positive responders predominate in western (cooler, wetter) locations. The negative growth trend in interior white and black spruce decreases the potential for wood-fueled energy generation.

◆ **Wurtz, T.L. 1988.** Effects of the microsite on the growth of planted white spruce seedlings. Unpubl. PhD Thesis. Univ. of Oregon. 200 pp.

Author abstract. Use of forest resources in interior Alaska is increasing, yet little information is available on the regeneration requirements of the main commercial species of this region, white spruce (*Picea glauca* [Moench] Voss). In particular, little is known about factors affecting the growth of planted seedlings. Portions of three floodplain sites were clearcut or shelterwood cut, and were subjected to one of four site preparation treatments. The four treatments represented a range in disturbance level from light (mechanical scarification) to severe (broadcast burning). White spruce seedlings were planted in the forest cutovers. Four features of each microsite were described: (1) microtopography; (2) associated vegetation; (3) light environment; and (4) soil profile. Seedling growth was monitored for three years. Seedling growth was unrelated to either the microtopography or the light environment of the microsite. Some measures of seedling growth were related to some species of associated vegetation. The microsite feature most consistently related to seedling growth was the mineral soil content of the 20 cm soil profile. This variable is a function of site age and the level to which organic soil has been removed from the profile by site preparation. Microsites in the severely burned area had the most mineral soil and the best seedling growth of any treatment area. Work by Dyrness, Viereck, Foote and Zasada (1988) on the same sites documented dramatic increases in soil temperature following severe broadcast burning. Together, these results suggest that soil temperature is the critical factor influencing establishment and early seedling growth on floodplain sites. The mineral soil content of the profile appears to be an effective, easily-measured indicator of soil temperature. The measurement of this microsite variable may help silviculturists choose and assess site preparation methods, and may help tree planters choose individual planting spots.

◆ **Young, B. D. 2012.** Diversity in the boreal forest of Alaska: distribution and impacts on ecosystem services. Unpubl. PhD thesis. Univ. of Alaska Fairbanks. 261 pp.

Author abstract. Within the forest management community, diversity is often considered as simply a list of species present at a location. In this study, diversity refers to species richness and evenness and takes into account vegetation structure (i.e. size, density, and complexity) that characterize a given forest ecosystem and can typically be measured using existing forest inventories. Within interior Alaska the largest forest inventories are the Cooperative Alaska Forest Inventory and the Wainwright Forest Inventory. The limited distribution of these inventories constrains the predictions that can be made. In this thesis, I examine forest diversity in three distinct frameworks; Recruitment, Patterns, and Production. In Chapter 1, I explore forest management decisions that may shape forest diversity and its role and impacts in the boreal forest. In Chapter 2, I evaluate and map the relationships between recruitment and species and tree size diversity using a geospatial approach. My results show a consistent positive relationship between recruitment and species diversity and a general negative relationship between recruitment and tree size diversity, indicating a tradeoff between species diversity and tree size diversity in their effects on recruitment. In Chapter 3, I modeled and mapped current and possible future forest diversity patterns within the boreal forest of Alaska using machine learning. The results indicate that the geographic patterns of the two diversity measures differ greatly for both current conditions and future scenarios and that these are more strongly influenced by human impacts than by ecological factors. In Chapter 4, I developed a method for mapping and predicting forest biomass for the boreal forest of interior Alaska using three different machine-learning techniques. I developed first time high resolution prediction maps at a 1 km^2 pixel size for aboveground woody biomass. My results indicate that the geographic patterns of biomass are strongly influenced by the tree size class diversity of a given stand. Finally, in Chapter 5, I argue that the methods and results developed for this dissertation can aid in our understanding of forest ecology and forest management decisions within the boreal region.

◆ **Young, B., J.J. Liang, and F.S. Chapin. 2011.** Effects of species and tree size diversity on recruitment in the Alaskan boreal forest: A geospatial approach. Forest Ecology and Management 262:1608-1617.

Author abstract. This study empirically evaluates and maps the relationships between recruitment and species and tree size diversity, as measured with the Shannon's index, within mixed poplar/birch and mixed spruce stands across the boreal forest of Alaska. Data were collected from 438 permanent sample plots re-measured at a 5-year interval. Significant explanatory factors of recruitment, including species and tree size diversity were first identified using hierarchical partitioning. The effects of tree diversity on recruitment were then studied using generalized linear models and universal kriging to account for non-spatial factors and for spatial autocorrelation. We found a consistent positive relationship between recruitment and species diversity and a general negative relationship between recruitment and tree size diversity, indicating a tradeoff between species diversity and tree size diversity in affecting recruitment. These relationships however were not uniform across the landscape, presumably because they were subject to strong spatial autocorrelation attributable to natural disturbances and environmental stressors. In general, diversity had least effect on recruitment in stressful environments where stress, rather than competition, most likely governed recruitment.

◆ **Youngblood, A. 1995.** Development patterns in young conifer-hardwood forests of interior Alaska. Journal of Vegetation Science, 6: 229–236.

Author abstract. The age structure and growth patterns of 53 young conifer-hardwood stands on upland, south-facing sites of interior Alaska were analyzed to determine the length of time for stand establishment after disturbance, the composition of early-successional stands compared to existing stands, and the potential for late-successional stands dominated by conifers. Mixed stands of *Picea glauca*, *Populus tremuloides* and *Betula papyrifera* represented five plant community types and developed as single cohorts after stand-replacement fires. In the *Populus tremuloides/Arctostaphylos uva-ursi* and *Populus tremuloides/Shepherdia canadensis* community types, hardwoods established rapidly and *Picea glauca* established slowly. In contrast, stands in the *Betula papyrifera-Populus tremuloides/Viburnum edule*, *Betula papyrifera-Populus tremuloides/Alnus crispa*, and *Picea glauca-Betula papyrifera/Hylocomium splendens* community types generally developed as a result of rapid, concurrent establishment of conifers and hardwoods. These single-cohort, mixed species development patterns are not consistent with continual establishment of conifers and are likely the result of unique life-history traits and frequent stand-replacement fires.

◆ **Zasada, J.C., T.L. Sharik and M. Nygren. 1993**. The reproductive process in boreal forest trees. Pages 85-125 in H.H. Shugart, R. Leemans, and G.B. Bonan, eds. A systems analysis of the boreal forest. Cambridge University Press, Cambridge, England.

Author abstract. The boreal forests of the world, geographically situated to the south of the Arctic and generally north of latitude 50 degrees, are considered to be one of the earth's most significant terrestrial ecosystems in terms of their potential for interaction with other global scale systems, such as climate and anthropogenic activity. This book, developed by an international panel of ecologists, provides a synthesis of the important patterns and processes which occur in boreal forests and reviews the principal mechanisms which control the forests' pattern in space and time. The effects of cold temperatures, soil ice, insects, plant competition, wildfires and climatic change on the boreal forests are discussed as a basis for the development of the first global scale computer model of the dynamical change of a biome, able to project the change of the boreal forest over timescales of decades to millennia, and over the global extent of this forest.

◆ **Zasada, J.C. and Gregory, R.A. 1972.** Paper birch seed production in the Tanana Valley, Alaska. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Research Note PNW-177, 7 pp.

Author abstract. A study of seedfall was conducted from 1958 to 1963 in four Betula papyrifera stands near Fairbanks, Alaska. Total seed crops varied between 542 and 72, 805 seeds per square meter; viable seed per square meter varied between 42 and 27, 520. Seed crops adequate for natural regeneration of 100-foot wide clearcuts occur in at least 1 out of 4 years in this portion of the taiga.

◆ **Zasada, J.C. 1988.** Embryo growth in Alaskan white spruce seeds. Canadian Journal of Forest Research, 1988, 18(1): 64-67, 10.1139/x88-010.

Author abstract. Embryo development in white spruce seeds was studied in five stands in interior Alaska. Cones and seeds were collected at 10- to 14-day intervals starting in mid-July and continuing until just before seed dispersal began. Significant differences were found in embryo development between stands, between trees within stands, and between cones within trees. The four stands at lower elevations produced seeds that had embryos filling 95% or more of the embryo cavity; this percentage was significantly higher than the highest elevation stand where embryos filled about 75% of the embryo cavity at the end of the growing season. Relative cotyledon length was generally greater than 25% in the lower elevation stands and slightly less than 20% in the high elevation stand. Although seed collection can be started when embryos fill 75% of the embryo cavity, the results of this and other studies suggest that collecting seeds when embryos are more mature will result in better quality seeds. Air and soil temperatures and soil moisture levels associated with embryo development are presented.

◆ **Zasada, J.C. 1984.** Site classification and regeneration practices on floodplain sites in interior Alaska . pp. 35-37 in: Pacific Northwest forest and range station general technical report PNW-177. M. Murray, ed. 56 pp.

Introduction. The floodplains of Alaska's rivers are some of the most productive forest sites in the state. Historically these forests, in particular white spruce *(Picea glauca),* were heavily utilized during the gold rush and settlement period of the early 1900s. As transportation of building and heating materials from outside of Alaska became more efficient, local forest utilization decreased. Present utilization is insignificant except near villages where forests are the only readily accessible source of wood. There is high potential to increase utilization of these stands. The impetus for this increase appears to stem from political and economic interest. Management experience and research information that can be applied to management of floodplain sites is limited. The most detailed research on any aspect of management on northern river floodplains (north of ***60'*** N latitude) was reported by Gardner (1983) for the Liard and Meister rivers in southern Yukon. Ganns (1977) reported on regeneration studies on Tanana River (Alaska) sites. Experience gained from management on uplands in Alaska .provides some insight into management alternatives for flood plains. However, ecological conditions on these two physiographically distinct areas are different in several important ways, and practices may not be directly transferable from one type of area to the other (Zasada et al. 1977).

In contrast to the lack of management experience is the availability of a relatively large body of basic ecological information for flood plain sites (Viereck 1970a, 1970b; Van Cleve et al. 1971, 1980; Van Cleve and Viereck 1972, 1980; Juday and Zasada 1984). These studies provide valuable information on site development and forest succession. However, they do not deal with secondary forest succession following such disturbances as fire and harvesting.
The purpose of this paper is to consider factors that affect white spruce regeneration on flood plains. To do this, we first need to consider, briefly, the development of forests on these sites - how white spruce stands originate and their fate in the absence of disturbance. In the second part of this paper, regeneration alternatives will be discussed using the Willow Island research project as an example. This project is primarily concerned with regeneration options following harvesting, but white spruce stand and site development have also been examined in some detail (Juday and Zasada 1984).

◆ **Zasada, J.C., and G.A. Schier. 1973.** Aspen root suckering in Alaska: effect of clone, collection date, and temperature . Northwest science, v. 47, no. 2, (May 1973), pp. 100-104.

Author abstract. Many of the aspen (Populus tremuloides Michx.) stands in Alaska originated from root suckers after the parent stands were destroyed by fire (Lutz, 1956; Gregory and Haack, 1965). Although there has been extensive research in other parts of the species range on the capacity for aspen to sucker, there has been no research conducted on Alaskan genotypes. To obtain this basic information, initial sucker development on excised roots from three Alaskan clones as affected by dare of collection, clone, and temperature was examined.

REFORESTATION METHODS AND RESULTS

◆ **Alaska Division of Forestry. 1992.** Tree improvement, nursery and research for interior and southcentral Alaska : a report . I vol. (various pagings)

Author introduction. This report presents the history and current status of renewable forest resource management activity and proposes research opportunities, operational tree-improvement, and nursery programs for interior and southcentral Alaska. It also includes specific proposals for a multipurpose facility at the University of Alaska Fairbanks and a "Teens for Trees" program for local rural youth. This report is not a plan nor does it address responsibilities, funding sources, or program implementation.

◆ **Alaska Division of Forestry. 1995.** Mat-Su regeneration surveys. Unpubl. Report. 12 pp. + notebook.

Compiler abstract. Short reports summarize data from 1995 regeneration surveys on timber sales in the Mat-Su Area.

◆ **Alaska Division of Forestry. 2007.** Timber sale history, Division of Forestry, Coastal Region/MSAO. Unpubl. Report. 13 pp.

Compiler abstract. Packet of information includes data on timber sales in the Mat-Su Area. Tables include data from regeneration surveys in harvest areas.

◆ **Alaska Reforestation Council Workshop. Anchorage, AK. 1999.** Stocking standards and reforestation methods for Alaska : proceedings of the Alaska Reforestation Council, April 29, 1999 Workshop, Anchorage, Alaska . Miscellaneous publ. Univ. of Alaska Fairbanks, Agriculture and Forestry Experiment Sta. 99-8. 85 pp.

Need abstract—Jeff Graham?

◆ **Alden, J.N. 1991.** Provisional tree seed zones and transfer guidelines for Alaska . United States Department of Agriculture, Forest Service, Pacific Northwest Research Station. GTR-270. 35 pp.

Author abstract. Four hundred and eighty-six provisional tree seed zones were delineated within 24 physiographic and climatic regions of Alaska and western Yukon Territory Estimated forest and potential forest land within altitudinal limits of tree species in Alaska was 51,853,000 hectares (128,130,000 acres) Seed transfer guidelines and standard labeling of seed collections are recommended to reduce losses from maladaptation and maintain the genetic identity and productivity of future forests in Alaska.

◆ **Alden, J. 1985.** Biology and management of white spruce seed crops for reforestation in subarctic taiga forests. Univ. of Alaska Fairbanks, Sch. of Agriculture and Land Resource Mgmt., Agric. and For. Exp. Sta. Bulletin 69. 51 pp.

Author abstract. Seed production is the most dramatic event in the life cycle of trees and is the first step in forest regeneration. Embryos of white spruce are fragile during germination, and they depend on vigorous seeds for survival and growth. Mortality of white spruce seeds and seedlings is high in northern forests because climate and microhabitat are often unfavorable for seed germination and seedling establishment. Large quantities of high-quality seed are required for natural and artificial regeneration of white spruce forests at high latitudes. The first chapter of this bulletin describes the reproductive process of white spruce and factors that affect cone and seed production and seed quality. Knowledge of the reproduction cycle and factors that affect seed production and quality of white spruce is essential for forecasting and managing seed crops. Evidence that white spruce is a genetically variable species in northern forests is summarized in the second chapter. This chapter includes recommendations for maintaining the gene pool of natural populations and for seed transfer in afforesting sites that do not have endemic populations. A procedure for delineating planting zones for adapted seed sources is described as an alternative for provisional seed zones that only reduce the risk of maladaptation from long-range seed transfer . The final chapter outlines steps in harvesting white spruce seed crops and can be used as a working manual . Practical procedures are described for evaluating quality and quantity of white spruce seed crops , certifying the geographic origin of seed parents , collecting cones , and processing seeds to maintain viability for many years. The genetic structure of white spruce and the environment-embryology relationships that effect seed production and maturation have not been studied in detail . The need for research in the areas of genetics, biochemistry, physiology, and ecology is discussed in each chapter. The results of such research will help to improve seed yields and make the management of white spruce crops more profitable in Alaska and Yukon.

◆ **Byrd, A.G. 2013.** Evaluating short rotation poplar biomass on an experimental land-fill cap near Anchorage, Alaska. Unpubl. M.S. Thesis. Univ. of Alaska Fairbanks. 55 pp.

Author abstract. Biomass energy has enjoyed a resurgence of scientific interest recently. Indeed, biomass may have the potential to replace diesel fuel as the primary source of heating in some parts of Alaska. In addition to forest biomass, short rotation crops have been considered as a sustainable source of woody biomass, and a potential sink for carbon sequestration. In this study, *Populus balsamifera* was evaluated as a short rotation crop for use as an energy source in Southcentral Alaska. Growth and yield rates were measured on an established *P. balsamifera* stand under a two-year rotation, yielding an annual biomass production of 5,530 kg/ha/yr. A fertilizer application study was conducted and demonstrated no effect on growth. Energy content of *P. balsamifera* measured 19,684 kJ/Kg, with a total energy yield of 217,715 MJ/ha after two years. Carbon sequestered below ground was estimated at least 5,338 kg/ha. Biomass may not be carbon neutral, but the carbon emitted from burning biomass is at least partially renewable. With use in high-efficiency boilers, there is potential for biomass to offset costs, and even save money by displacing diesel heating fuel.

◆ **Calogeropoulos, C., D. F. Greene, C. Messier, and S. Brais. 2004**. The effects of harvest intensity and seedbed type on germination and cumulative survivorship of white spruce and balsam fir in northwestern Quebec. Canadian Journal of Forest Research 34:1467-1476.

Author abstract. The effects of different harvest intensities, including uncut, 1/3 and 2/3 partial cuts, clearcuts with and without slash, were investigated on the germination and cumulative survivorship of white spruce and balsam fir over 2 consecutive years. We also investigated the regenerative capacity of both species on three different seedbeds across all harvest intensities. The seedbeds included were mineral, humus, and organic soil. At the germination stage, both species were strongly affected by seedbed type ($p < 0.032$). The germination rates of fir seeds in partial cuts were significantly greater than clearcut treatments, but spruce remained unaffected at this stage by harvest intensity. The addition of slash improved the germination rates of fir relative to the clear-cut plots without slash. The germination rates the following year were reduced on mineral soil for spruce. The cumulative survivorship at the end of the third summer still showed a significant seedbed response for both species ($p < 0.007$) and a significant harvest response for fir ($p < 0.005$). The cumulative survivorship of the second fir cohort was no longer affected by either harvest or seedbed type. Spruce, however, was still affected by seedbed type ($p = 0.006$). The data from this study provide us with a more detailed description of the fate of cohorts recruited following a harvest operation. Still, what remains to be studied is the fate of these cohorts over the next 5–10 years.

◆ **Cole, E., A. Youngblood, and M. Newton. 2003.** Effects of competing vegetation on juvenile white spruce (Picea glauca (Moench) Voss) growth in Alaska. Annals of Forest Science 60:573-583.

Author abstract. We examined the impacts of competing vegetation on survival and juvenile growth of white spruce (Picea glauca (Moench) Voss) on 3 units in south central Alaska and on 3 units in interior Alaska. Treatments consisted of herbicide site preparation and release treatments, and also included a treatment in which competition was minimized for 5 years (weed-free treatment). At all units, the weed-free treatment resulted in significant increases in white spruce height and basal diameter by ages 10 or 11 compared to untreated plots. Average heights and diameters in the weed-free treatments were 1.5 to 3.8 times and 2.0 to 3.8 times those in the untreated plots, respectively. Results from the other treatments differed by unit based on the efficacy of a particular treatment on the vegetation at that unit. For all units, regression equations indicated a significant decrease in diameter at year 10 or 11 with increasing competitive cover and overtopping.

◆ **Cole, E.C., Newton, M., Youngblood, A., 1999.** Regenerating white spruce, paper birch, and willow in south-central Alaska. Natl. Research Council Canada, pp. 993-1001.

Author abstract. The current spruce bark beetle (Dendroctonus rufipennis Kirby) epidemic in interior Alaska is leaving large expanses of dead spruce with little spruce regeneration. Many of these areas are habitat for moose (Alces alces). To establish spruce regeneration and improve browse production for moose, paper birch (Betula papyrifera Marsh), willow (Salix spp.), and three stocktypes (plug+1 bareroot, and 1+0 plugs from two nurseries) of white spruce (Picea glauca (Moench) Voss) were planted in freshly cutover areas on Fort Richardson, near Anchorage. Four vegetation management treatments were compared: broadcast site preparation with herbicides, banded site preparation with herbicides, mechanical scarification, and untreated control. Spruce seedlings had the greatest growth in the broadcast site preparation treatment ($p < 0.01$). Stocktype was the most important factor in spruce growth, with bareroot transplant seedlings being the tallest and largest 5 years after planting ($p < 0.001$). In the first 3 years, relative stem volume growth was greater for plug seedlings than for bareroot seedlings ($p < 0.001$). By year 4, relative growth rates were similar among all stocktypes. Treatment effects for paper birch and willow were confounded by moose browsing. Results indicate spruce can be regenerated and moose browse enhanced simultaneously in forests in interior Alaska.

◆ **Densmore, R. V., G.P. Juday, and J.G. Zasada. 1999.** Regeneration alternatives for upland white spruce after burning and logging in interior Alaska. Can. J. For. Res. 29(4): 413-423, 10.

Author abstract: Site-preparation and regeneration methods for white spruce (*Picea glauca* (Moench) Voss) were tested near Fairbanks, Alaska, on two upland sites which had been burned in a wildfire and salvage logged. After 5 and 10 years, white spruce regeneration did not differ among the four scarification methods but tended to be lower without scarification. Survival of container-grown planted seedlings stabilized after 3 years at 93% with scarification and at 76% without scarification. Broadcast seeding was also successful, with one or more seedlings on 80% of the scarified 6-m^2 subplots and on 60% of the unscarified subplots after 12 years. Natural regeneration after 12 years exceeded expectations, with seedlings on 50% of the 6-m^2 subplots 150 m from a seed source and on 28% of the subplots 230 m from a seed source. After 5 years, 37% of the scarified unsheltered seed spots and 52% of the scarified seed spots with cone shelters had one or more seedlings, but only 16% of the unscarified seed spots had seedlings, with and without funnel shelters. Growth rates for all seedlings were higher than on similar unburned sites. The results show positive effects of burning in interior Alaska, and suggest planting seedlings, broadcast seeding, and natural seedfall, alone or in combination, as viable options for similar sites.

◆ **Fox, John. 1980.** Forest regeneration of upland areas following logging in Interior Alaska. Agroborealis. 12/1979; 12:1

Publisher abstract: A reconnaissance study of post-harvest natural regeneration of upland areas near the Parks Highway made to determine stocking densities of desirable species. Data are tabulated showing frequency and density of tree and non-tree species. While revegetation has occurred, the regeneration of commercial tree species is variable (mainly white spruce, birch, and aspen (Populus tremuloides)). Implications for ecology and management are discussed.

◆ **Gardner, A. C. 1983.** White spruce regeneration options on river floodplains in the Yukon Territory. Environment Canada, Canadian Forestry Service, Pacific Forest Research Centre, Victoria, B.C.

Author abstract. White spruce regeneration options tested on river floodplains of the Yukon Territory, including natural seeding, spot and broadcast seeding and planting on scarified and unscarified ground, were replicated for two years on two sites. Five years after establishment the results indicate that scarification increases seedling survival and growth, that broadcast seeding outperformed spot and natural seeding and that spring planting of container stock is a reliable regeneration technique. The infeasibility of plantation reforestation in the Yukon at present suggests a need for development and refinement of seeding techniques.

◆ **Gradowski, T., Lieffers, V.J., Landhäusser, S.M., Sidders, D., Volney, J., Spence, J.R., 2010.** Regeneration of Populus nine years after variable retention harvest in boreal mixedwood forests. For. Ecol. Manage. 259, 383-389.

Author abstract. Aspen and balsam poplar regeneration from root suckers were assessed in boreal mixedwood forests nine years after logging in a variable retention experiment (EMEND Project—Ecosystem Management Emulating Natural Disturbance) located north of Peace River, Alberta, Canada. Five levels of retention of mature trees (2%, 10%, 20%, 50% or 75% of the original basal area) were applied in stands dominated by aspen, white spruce or mixtures of the two species. Basal area of aspen (or that of aspen plus balsam poplar combined) prior to logging strongly influenced sucker density of aspen (or aspen + balsam poplar combined) and in some cases their growth. Nine years after harvest there was a decline in sucker density and volume ha-1 with increasing retention levels of aspen (or both poplars combined); sucker density declined by 50% when only 20% of the original basal area was left in the stand. Retaining mature spruce trees in the stand had little influence on the number of suckers but did affect their total volume ha-1. Thus, we suggest that by knowing stand aspen and balsam poplar density prior to logging and varying levels of retention of aspen and balsam poplar or conifers at harvest, the density of Populus regeneration can be predicted by managers, thereby allowing them to create a range of mixedwood conditions.

◆ **Graham, J.S., and T.L. Wurtz. 2003.** Survival and Growth of Selected White Spruce Container Stock Types in Interior Alaska. Tree Planters' Notes 50(1): 44-49; 2003.

Author abstract. Survival and growth of white spruce (Picea glauca (Moench) Voss) seedlings raised as 4 different-sized container stock types were followed on 5 harvested sites in the Cache Creek drainage of interior Alaska. Stock types evaluated were 1-0 Ray Leach Pine Cells® ($65\ cm^3$, $4\ in^3$) and 1-0 Styroblock® sizes 313B (65 cm3, 4 in3), 415B (98 cm3, 6 in3), and 415D ($164\ cm^3$, $10\ in^3$). After 5 years, survival and height growth were mixed. Ray Leach Pine Cells had a significantly higher rate of survival than seedlings grown in Styroblock 313B containers, but there were no differences among the survival of Ray Leach and the other 2 Styroblock sizes, nor among the Styroblock sizes themselves. Survival of all 4 stock types varied dramatically among sites. Although this experiment was not designed to evaluate site factors, lowest survival rates (25% to 40%) may have been related to the bluejoint grass (Calamagrostis canadensis (Michx.) Beauv.) and fireweed (Epilobium angustifolium L.) cover found in 2 of the sites, and highest survival (90%) may have been related to the slight topographic elevation of 1 site. Seedlings grown in Styroblock containers were substantially taller at planting than those grown in Ray Leach containers; this difference was maintained after 5 y. Stem diameter did not differ significantly among stock types, either at planting or after 5 y. Our results reiterate that seedling out planting performance is a complex f unction of many factors, including stock type, competing vegetation, and microsite, and suggest that more research on the performance of different stock types in Alaska is needed before standard stock types can be identified for various site conditions. Tree Planters' Notes 50(1): 44-49; 2003.

◆ **Greene, D.F. and E.A. Johnson. 1998.** Seed mass and early survivorship of tree species in upland clearings and shelterwoods. CJFR 28(9): 1307-1316, 10.1139/x98-106

Author abstract. We examined recommended sowing densities of 25 North American tree species (26 observations) to measure the relationship between juvenile survivorship and seed mass in large clearings and shelterwoods. Two models for expressing the relationship (simple power law or a cumulative negative exponential adjusted to account for rodent-repellent application and seedbed type) all showed that survivorship is highly dependent on seed mass. For a small seed, mineral soil and thin humus confer roughly equally high survivorship. Leaf litter is very poor, and undisturbed thick moss appears to be the worst possible organic seedbed on upland sites. An examination of 30 records of *Picea glauca* (Moench) Voss survivorship (3- to 6-year-old cohorts) on mineral soil revealed substantial intraspecific variation with only 50% of the values within twofold of the predicted value.

◆ **Hollingsworth, J. 2002.** Early height growth patterns of planted white spruce seedlings in Interior Alaska . Unpubl. M.S. Thesis. Univ. of Alaska Fairbanks. 174 pp.

Author abstract. This study looked at early height growth of planted white spruce Picea glauca (Moench) Voss around the Fairbanks area. The effort focused on two Levels-of-Growing-Stock (LOGS) experimental plantations located in the Bonanza Creek Experimental Forest that incorporated an espacement study. Annual total height was also measured on 16 operational plantations and then compared to LOGS plantations. Average annual total height at Site 2 of the LOGS plantations was significantly greater than at Site 1. A significant difference in height growth between these sites was attributed to differences in aspect. Results showed significant annual total height differences among the espacement plots within the LOGS plantation. The narrowest spacing 1.2 X 1.2 m and widest spacing 3.7 X 3.7 showed a lower annual total height while spacings 1.8 X 1.8 m, 2.4 X 2.4 m, and 3.0 X 3.0 m showed a greater annual total height at age ten. The range of annual total height found at the LOGS sites was not significantly different than the range of annual total height found at the 16 operational plantations. Additionally, path analysis was used to quantify the direct and indirect effects of multiple environmental variables (i.e., percent slope, slope position, competition, aspect, and soil moisture) on growth rate at the operational plantations. It was found that slope position, percent slope, and competition had significant direct effects on growth rate. These results provide insight for resource managers when predicting the height growth of planted white spruce

◆ **Jandreau, R., and A. Arians. 2006**. 2004 Regeneration Survey: Forest Lands on the Kenai Peninsula Exempt from the Reforestation Standards of the Alaska Forest Resources and Practices Act. ADNR Division of Forestry and USDA Forest Service State and Private Forestry, Anchorage, AK. Unpublished. 20 pp.

Author abstract: Some, but not all, forest lands harvested after the spruce bark beetle infestation on the Kenai Peninsula regenerated naturally to the minimum requirements of the Alaska Forest Resources and Practices Act (FRPA). The forest lands that regenerated naturally were those that contained some trees that had survived the beetle outbreak to be left as residuals in the harvested stands.

Regeneration standards under FRPA require that two criteria be met: 1) that the numbers of seedlings and residual trees are adequate, and 2) that those seedlings and residual trees are evenly distributed. For the stands with residual trees, both the numbers and distribution of seedlings and residuals were adequate without requiring additional reforestation work. The areas with few residuals did not meet the standards because the distribution of the residual trees and seedlings was patchy, and for plots harvested in the summer without residuals, the number of seedlings and residuals was inadequate. These results indicate that the number of residuals left after harvest plays an important role in whether the reforestation standards can be met naturally.

The numbers of seedlings found in stands with residuals were significantly higher than in stands with few residuals, probably because of the additional seed source provided by the mature trees, and also possibly because of the shade provided by the trees, which appears to limit the abundance of grass (mostly *Calamagrostis canadensis*). The grass appears to be a competitor with seedlings for resources, since seedlings were less abundant in plots dominated by grass than by other types of vegetation. Stands with few residual trees present had higher occurrences of grass as the dominant vegetation. The season of harvest, our surrogate for amount of soil disturbance during harvest, did not appear to directly influence seedling abundance. However, grass-dominated plots were less abundant in plots that were harvested in the summer (and thus had probably experienced more scarification as a by-product of harvest). Season of harvest, then, may indirectly affect seedling regeneration because of its effect on grass abundance.

◆ **Johnstone, J. 2005.** Effects of aspen (*Populus tremuloides*) sucker removal on postfire conifer regeneration in central Alaska. CJFR 2005, 35(2): 483-486, 10.1139/x04-171.

Author abstract. This experiment tests the effects of early canopy development by asexually regenerating aspen (*Populus tremuloides* Michx.) on conifer recruitment after fire in central Alaska. The establishment and growth of three conifer species were observed in response to aboveground removal of aspen suckers for three seasons after burning by wildfire. Of the three species, *Pinus contorta* Dougl. ex Loud. had the most widespread seed germination and showed the strongest negative response to the presence of the aspen canopy. *Picea mariana* (Mill.) BSP and *Picea glauca* (Moench) Voss had low germination and weak or neutral responses to aspen removal. Seedlings of all species accumulated more biomass in the removal treatment. Results from the experiment suggest that competition by aspen early after disturbance can significantly reduce conifer recruitment and growth, an effect that may reinforce the long-term dominance of aspen in asexually regenerating stands.

◆ **Juday, G.P. R.V. Densmore, and J.C. Zasada. 2013**. White Spruce Regeneration Silviculture Techniques 25 years after Wildfire: the Rosie Creek Fire Tree Regeneration Installation. In: Camp, A.E.; Irland, L.C.; Carroll, C.J.W. (eds.) Long-term Silvicultural & Ecological Studies: Results for Science and Management, Volume 2.

Author abstract. This article describes the origin and potential future of a large assisted regeneration installation for white spruce, the largest experimental silvicultural installation known to the authors in boreal Alaska.

◆ **Juday, G.P. 2005.** Reserve West Seedling Establishment and Growth after Fire 1988 - 2009, Bonanza Creek LTER - University of Alaska Fairbanks. **BNZ:91**, http://www.lter.uaf.edu/data_detail.cfm?datafile_pkey=91

Author abstract. In 1983 an 8,600 acre human-caused wildfire, the Rosie Creek Fire, burned through about 1/3 of the Bonanza Creek Experimental Forest unit of the Bonanza Creek LTER in central Alaska. The stand that burned was a productive white spruce dominated stand about 200 years old. This study of tree regeneration was initiated in 1989 in a 100m by 100m reference hectare at the perimeter of the Rosie Creek Burn, located between 100m and 200m from the surviving stand edge. The Reserve West reference hectare was reserved from salvage logging and artificial reforestation. All regenerating white spruce trees in the hectare have been mapped and seedling survival and height elongation have been measured annually since 1989 (1988 and 1987 tree heights were back calculated from internodes). Seedlings are tracked by a subdivision of the hectare into 100 cells of 10m by 10m. The total number of trees that have been tracked in the database is 2,527. This is one of the largest and longest complete data series examining forest regeneration in the boreal region.

◆ **Landis, T.D., R.K. Dumroese, and D.L. Haase. 2010.** Seedling Processing, Storage, and Outplanting, The Container Tree Nursery Manual . USDA Agriculture Handbook 674, Vol. 7.

Introduction. The Container Tree Nursery Manual has been functionally organized to follow the normal sequence of nursery development, seedling propagation, and outplanting. Volume one discusses the various steps that should be followed in developing a nursery facility. Volume two is concerned with the selection of types of containers and growing media. Volume three and volume four analyze the "limiting factors" that affect seedling growth and discuss how they can be manipulated in container nurseries. Volume five examines the various biological organisms that can affect seedlings, either negatively as pests or positively as mycorrhizae. Volume six shows how to develop growing schedules and how seedlings are propagated through the three growth phases. Volume seven covers the time from when the crop is hardened-off and ready for harvest to when they go in the ground.

◆ **Lieffers, V. J. and K. J. Stadt. 1994.** Growth of understory Picea glauca, Calamagrostis canadensis, and Epilobium angustifolium in relation to overstory light transmission. Canadian Journal of Forest Research 24:1193-1198.

Author abstract. The potential for use of a partial canopy for controlling growth of Calamagrostis canadensis (Michx.) Beauv., and Epilobium angustifolium L. among regenerating Picea glauca (Moench) Voss saplings was assessed in the understory of 24 established stands in the P. glauca - Viburnum - Rubus pubescens association of the lower boreal cordilleran ecoregion of Alberta. Stand overstories were dominated by Populus tremuloides Michx., P. glauca, or were a mixture of these two species. The composition, basal area, and light transmission of the overstory of each stand were measured. Hardwood-dominated overstories transmitted between 14 and 40% of incoming light while P. glauca canopies transmitted between 5 and 11% of light. Cover and height of C. canadensis and E. angustifolium decreased with decreasing light transmission; at 40% light, both species were greatly reduced compared with open-grown conditions and both were virtually eliminated from stands with less than 10% light. The annual height increment of P. glauca saplings increased from 5 cm at 10% light to 25 cm at 40% light; the latter increment was approximately equal to growth in 100% light conditions. The number of buds, the diameter of the current leader, and the height to diameter ratio of the tree also increased with light transmittance.

◆ **Maisch, J.C. 1993.** Reforestation on Alaska Native lands. Alaska branching out. Aug. 1993. 12(3): 1.

Compiler summary. This article summarizes tree planting operations on Toghotthele Corporation lands and a native allotment near Nenana in 1992-93. Approximately 205 acres were scheduled for planting in 1993 with white spruce seedlings grown in containers and purchased from Pelton Reforestation Ltd. of British Columbia, Canada. The one year old seedlings were grown from seed collected from the same lands targeted for reforestation.

The planting crew is comprised of shareholders of the Toghotthele Corporation and the forestry program staff of the Tanana Chiefs Conference, Inc (TCC). In 1992 the crew planted 100,000 seedlings on other units of Toghotthele lands. Approximately 680 seedlings are planted per acre using 8’ by 8’ spacing. Over a 6 hour period, each planter is able to sow approximately 650 seedlings. A planter earns 15 cents for each seedling planted.

TCC monitors planting operations and collected planting cost data which will be included in a report on reforestation costs on private land in Interior Alaska for publication in the Northern Journal of Applied Forestry.

◆ **Maisch, J. C. 1993.** Interior Alaska tree planting: a green experience. Alaska timber times 1993, (Aug. 1993) p. 2

Need abstract – check with CR?

◆ **Martin-DeMoor, J., V. J. Lieffers, and S. E. Macdonald. 2010.** Natural regeneration of white spruce in aspen-dominated boreal mixedwoods following harvesting. Canadian Journal of Forest Research 40:585-594.

Author abstract. In some boreal forests sites, there are considerable amounts of natural regeneration of white spruce (Picea glauca (Moench) Voss) after logging, even without silvicultural treatments to encourage establishment. We assessed the factors controlling the amount of this regeneration 8–15 years postharvest on previously aspen-dominated (Populus tremuloides Michx.) boreal mixedwood sites. We surveyed 162 transects across 81 cutovers, exploring the effects of mast years, season of harvest, distribution of seed trees, weather conditions around the time of harvest, and abundance of grass or woody vegetation on white spruce regeneration. Substantial amounts of naturally regenerated white spruce were found; however, sites with no seed trees had virtually no spruce regeneration. Average stocking was 7% (percentage of 9 m2 plots along a transect across a cutover that had at least one seedling), ranging from 0% to 62%. Stocking levels were higher in cutblocks that had been harvested in the summer, prior to seedfall of a mast year, and where there was a seed source within 60 m. Stocking was lower when conditions were cool and wet the year before and 2 years after harvest and when the site contained extensive cover of grass or woody vegetation.

◆ **Martinsson, O., Packee, E.C., Gasbarro, A.,Lawson, T., coords. 1989.** Forest regeneration at northern latitudes close to timber line. Proceedings, 7th annual workshop on silviculture and management of northern forests: 1985 June 16-20; Lulea, Gallivare, and Ostersund, Sweden. Gen. Tech. Rep. PNW-GTR-247. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 73 p

Compiler abstract. These proceedings include a series of papers on reforestation and afforestation in Scandinavia, primarily with Scots pine *(Pinus sylvestris)*. The collection also includes papers on secondary Korean pine-decidusous forests in Korea, and regeneration of Dahurian larch *(Larix gmelini)* in China.

◆ **Murray, M. 1980.** Forest regeneration at high latitudes . Pacific Northwest Range and Experiment Station. Portland, OR. 56 pp.

Summary. The proceedings of a fifth international workshop sponsored by the School of Agriculture and Land Resources, University of Alaska-Fairbanks in cooperation with the Division of Forestry, State of Alaska and the Alaska State Society of American Foresters, August 15, 16, 17, 1983, Fairbanks, Alaska, U.S.A.

◆ **Newton, M. 1996.** Adaptability of tree seedlings for forest regeneration in southcentral Alaska . Alaska branching out. 15(3): 1-2.

Conifer regeneration in Alaska, like everywhere else, is subject to many environmental problems during the decades immediately following establishment. Herbaceous and shrubby vegetation, in particular, represent the largest single cause of regeneration failure. After beetles have begun to attack mature stands, crowns open gradually over a period of several years, perhaps ending with negligible residual overstory. The opening process tends to favor shade-tolerant species already present in understories, and also invite invader species. Herbaceous species, especially *Calamagrostis canadensis* and *Epilobium angustifolium* are especially abundant after spruce has collapsed. When these herbs are mixed with residual and invasive alders, regeneration has negligible chance of establishment. When added to the tendency for large, seed-bearing spruces to be among the first to die, natural regeneration are scant even where understory cover may be light. On the more productive sites, the beetle-kill stands may be merchantable and be suitable for logging. On these sites, the productive soils are especially prone to herb development. After logging, there is a brief window of opportunity when competition is compatible with establishment of new natural seedling. In the absence of a decent seed year or source, planting is the only way of capturing this opportunity without major investments in vegetation control. Planting is usually done with containerized spruce seedlings. These may fare reasonably well if planted immediately after logging so that they are becoming established while cover is developing. Large plugs grow better than small ones, so cost control should not be allowed to sacrifice size. However, waiting even a year or two greatly increases the risks to any small plant, and especially those in which we have an investment. Safe, effective techniques of weeding greatly increase chances of success and growth rates. Use of large transplant seedling, such as plugs that have been transplanted a year or more in a bareroot nursery (p-1 or p-2 for those spending one or two years in transplant beds) are much larger, and have substantial growth advantages. Their relative advantages may be greatest if planted where herb cover has already developed, i.e. their use substitutes for weed control without the cost of weeding. When we combine transplants with either weed control, or planting before weeds develop, we observe that growth is greatly increased and dominance over early successional cover is assured. However, planting is costly, and transplants are more costly than plugs. It is likely that transplants will be less costly per successfully established dominant tree than alternative regeneration strategies if sites have some cover on them. Transplants grown with little competition are also potentially able to make the site appear to be much more productive than natural stands would indicate, if Oregon experience and preliminary Alaska data are valid. On marginal sites, dense plantations of transplants would cost as much to establish as the stands would yield 100 years hence. Thus, where the objective is to perpetuate the white spruce forest, a low-density planting of the largest available stock is appropriate for sites that have already developed some cover. Low-density plug planting will likely succeed where cover is mostly absent. But cost realities favor the evaluation of aerial seeding on newly logged sites as perhaps the only feasible way of reforesting the large areas involved. At present, no data exist with which to compare stocking distribution and growth after dissemination of treated seed with those of planted stock.

◆ **Nichols, T.F. 2005.** Aspen coppice with coarse woody debris : a silvicultural system for interior Alaska moose browse production . Unpubl. M.S. Thesis. Univ. of Alaska Fairbanks. 92 pp.

Author abstract. Browse production and use by moose (Alces alces gigas) in interior Alaska was investigated in 4 and 2-year-old quaking aspen (Populus tremuloides) coppice stands following clear-felling without removal of the mature aspen stems. Moose winter browse utilization, as related to distance from cover, coarse woody debris (CWD), and browse species composition, was quantified. Aspen terminal leaders were sampled to relate current annual growth (CAG) dry biomass (g) to leader diameter (mm). Stem density, current annual browse production, and browse use were estimated. Browse use was determined as 1) proportion of aspen stems browsed (stand scale), 2) proportion of browsed leaders per stem (stem scale), and 3) diameter-at-point-of-browsing (leader scale). Aspen sucker density ranged from 23,000-43,000 stems/ha. Terminal leader diameter was found to be a good estimator of individual stem CAG biomass. CWD did not impede moose utilization of stems. Browse use declined from mature stand edge to center (100 m). Beyond 15 m from mature stand edge browse use was low compared to that within 15 m of the stand edge. Clear-felling without removal of stems is a viable silvicultural method to reinitiate seral aspen in lieu of prescribed fire or mechanical treatments on south-facing hillsides.

◆ **Packee, E.C. 2001.** Reforestation stocking standards. Agroborealis 33(2):23- 24.

Compiler excerpt. The objective of this study is to determine for Alaska's Northern Forest species the effect of planting espacement on stem size and characteristics, yield per acre, stand structure, and wood quality. A second objective is to recommend espacement guidelines for both Alaska's Northern Forest and Coastal Forest species. Espacement impacts forest tree characteristics which in turn affect stand structure, wood quality, wood volume per acre, and ecological process (especially succession and soil processes).

Levels-of-Growing Stock (LOGS) plantations with espacements of 4x4, 6x6, 8x8, lOxlO, 12xl2 feet were established at two locations (Bonanza Creek near Fairbanks and at Tok). Survival and height have been measured annually. Once the majority of trees reach one-inch in diameter at breast height or 15 years of age, diameter will be measured and plots will then be measured at three or five year intervals. An ongoing literature review addresses the impact of espacement on tree characteristics. To ensure that aboveground competition is only that of the species being studied, hardwoods and conifers are routinely removed.

Plots at Bonanza Creek and Tok were remeasured and cleaned of competing vegetation. The 10-year results for Bonanza Creek were published. At Bonanza Creek, height growth of white spruce at 15 years of age continues to be least at the narrowest and widest espacements. Diameter growth at Bonanza Creek will be measured in spring 2001 before growth begins-most trees are measurable, with many trees over one inch in diameter. Understory vegetation distinctly differs between the widest and narrowest espacements; at narrowest espacement crown closure has occurred and self-pruning has begun. Observations in spruce indicate that gall aphids *(Adeleges* and/or *Pineus)* severely attack spruce in open-grown conditions; a senior thesis has been proposed to determine the insect and the impact.

Initial espacement guidelines are a discussion point in terms of the Alaska Forest Practice Regulations and Guidelines. At the narrowest espacement, the grass, *Calamagrostis canadensis,* a commonly strong competitor, is weak and being crowded out whereas in the wider espacements it is present, forms a sod, and is a vigorous competitor for summer moisture. This suggests that dense stocking of spruce may biologically control the grass.

.

◆ **Packee, E.C. 1999.** Initial forest stand density and wood quality: a preliminary report. Agroborealis 31 (1): 24-27.

Compiler excerpt. In 1984, the Agricultural and Forestry Experiment Station (AFES) began studying the Growth and Yield of Alaska's Northern Forest. Part of that program is a Levels-of-Growing-Stock (LOGS) study. A LOGS study addresses stand density regulation. The AFES study has two components: espacement, which refers to initial stocking and spacing, which refers to precommercial thinning. Both affect growth rates and tree characteristics. Individual tree characteristics impact wood quality. In 1998, a review of the international literature on the effects of espacement on wood quality, especially Alaska species, was initiated. Emphases are on the impacts of espacement and spacing on per acre fiber yield and wood quality; initial stocking levels to obtain high volume per acre yields of quality fiber are suggested.

Preliminary Espacement Guidelines for Alaska Species (Northern Forest)

Species	**Stems/acre**	**Spacing in feet**
Tamarack	680	8 x 8
White spruce	680	8 x 8
Black spruce	800-680	7 x 7 – 8 x 8
Paper birch	435	10 x 10
Balsam poplar	300	12 x 12
Quaking aspen	540	9 x 9

These guidelines are based on the literature, interpretation of guidelines from other regions, guidelines for similar species, information from various private entities, and personal observations across North America. Several colleagues in the private sector have indicated that their organizations have changed from being proponents of fast growth of individual trees to advocates of high volume per acre and associated higher quality wood fiber. Suggested espacements can be used, also, as stocking targets for survival at the free-to-grow stage of stand development or as early stand spacing targets. Tree geometry, tree height, crown diameter, and crown volume which define growing-space utilization, is largely the basis for the recommendations. To fully utilize the site requires crow occupation of available growing space. The guidelines are for single-species stands. Mixed stands, depending upon the species' shade tolerance. Can have an average, lesser, or greater espacement.

Encouragement of side-shading to cause natural pruning of branches, at least on the butt log (12 to 16 feet), is also desirable. Pruning of the best 200 to 300 crop trees per acre may be an attractive investment alternative to spacing or thinning or may be used in combination with spacing. Pruning desirability is species dependent as well as market dependent.

◆ **Paquette, A., A. Bouchard, and A. Cogliastro. 2006.** SURVIVAL AND GROWTH OF UNDER-PLANTED TREES: A META-ANALYSIS ACROSS FOUR BIOMES. Ecological Applications 16:1575-1589.

Author abstract. The transformation of natural forest regeneration processes by human activities has created the need to develop and implement new models of forest management. Alternative silvicultural systems such as variable retention harvest, partial and patch cuts, and older forest management practices such as under-planting, are used in many forests around the world, particularly in North American oak stands, the boreal and coastal temperate rain forests of Canada and the United States, and in many degraded tropical regions of Asia and the Americas. Specific objectives are pursued in each of these biomes, but some are common to most regions, such as preservation of cover and structure and their associated benefits for natural or artificial regeneration due to moderation of the microclimate, development of optimal light and competition conditions, and reduced predation by herbivores. Shelterwoods are often presented as an alternative to clear-cutting to improve the survival of planted trees. A meta-analysis of published results with randomization tests was performed to test the relationship between overstory density and planted seedling growth and survival. Multiple comparisons were also used to reveal optimal levels of overstory density, if they exist. A majority of studies show that survival and growth improve as stand density decreases to an intermediate level, below which they either drop or stabilize. This level seems optimal in most conditions, as it is also more apt to fulfill other objectives imposed on today's forest activities, such as the conservation of forest processes and structures, and the reconstruction of degraded stands through the accelerated return of mid- to late-successional species.

◆ **Peltzer, D.A., Bast, M.L., Wilson, S.D., Gerry, A.K., 2000.** Plant diversity and tree responses following contrasting disturbances in boreal forest. For. Ecol. Manage. 127, 191-203.

Author abstract. We determined the abundance and diversity of vascular plants in seven types of disturbance in mixed-wood boreal forest. Disturbance treatments included wildfire, natural regeneration after harvest and several methods of silvicultural site preparation. Relative to undisturbed forest, all disturbance treatments increased plant diversity to about the same extent. The abundance of plant growth-forms differed significantly between disturbance treatments. Silvicultural treatments involving soil disturbance (disk-trenching, drum-chopping and blading) had higher cover of grasses and annual forbs; naturally regenerated and cultivated treatments contained more perennial forbs and shrubs. Thus, different post-disturbance plant communities established following contrasting types of disturbance. Plant community biomass and tree growth varied among disturbance treatments. Shoot mass of aspen (Populus tremuloides Michx.) and the root mass of all species declined significantly with increasing soil disturbance intensity. Aspen and white spruce (Picea glauca (Moench) Voss) differed in their response to disturbance. Aspen growth was similar among disturbance treatments. In contrast, aspen density was significantly lower in disk-trenched and bladed treatments than in burned or naturally regenerated treatments, and aspen basal area was significantly lower only in drum-chopped treatments. White spruce grew fastest in drum-chopped sites. Burned treatments had the highest recruitment of volunteer spruce seedlings (up to 3200 ha(-1)), but not significantly higher than in other disturbance treatments. Taken together these results suggest that the most intensive silvicultural treatments had the expected effects of reducing aspen abundance and increasing the growth of spruce, but also contained more grasses and forbs and had lower total root mass than burned or naturally regenerating sites. Further work is needed to examine

long-term productivity and the persistence of both native and persistent weedy species following contrasting types of disturbance.

◆ **Perala, Donald A., and Alm, Alvin A. 1990.** Regeneration Silviculture of Birch: A Review. Forest Ecology and Management, 32: 39-77.

Author abstract. The birches are most commonly regenerated using even-aged systems, primarily clearcutting. Clearcut sizes range from 16 ha down to 0.4-ha patches. Seed trees or shelterwoods are sometimes used to provide additional seed and site protection. Uneven-aged systems are not recommended, with the exception of group selection for yellow birch. Coppice systems do not provide full stocking except in short-rotation biomass culture, but coppice provides acceptable supplemental regeneration.

Natural regeneration by seeding prevails because it is economical and highly reliable where the water balance is favorable. Yellow birch sometimes regenerates in advance, but otherwise the canopy, understory, and seedbed must be manipulated to meet germination and seedling-establishment requirements. Suitable seedbeds are prepared by burning, by mechanical site-preparation equipment, and sometimes by the logging process itself. Draining often is all that is necessary to regenerate peatlands. Seedlings should be protected from grazing or browsing. Relatively few stands are regenerated artificially. Direct seeding (either broadcast- or spot-sowing) is usually reliable. Planting is more common and gives the opportunity to introduce exotic or genetically improved stock. In species trials, silver birch has consistently grown faster - and yellow birch slower - than either hairy birch or paper birch. Phenotypically selected natural stands and controlled pollination produce progeny that grow in volume from 30 to 80% faster than average. Thorough site preparation, fertilization, mulching, weed control, and protection from animals benefit seedling growth. Both bare-root and container-grown stock are planted successfully.

Birch is highly regarded for afforesting mine spoils, drained or worked-out peatlands, abandoned and abused agricultural lands, heaths, previously flooded lands, and areas with high air pollution. Fertilizers are often applied to improve site quality. Birch nurse crops benefit conifers by protecting them from frost, insects, and pathogens; by improving the soil through nutrient cycling; and by increasing stand wind-firmness on shallow soils. The optimum proportion of birch in mixed stands is 17–25%. Overly dense birch should be controlled with chemicals, by hand, or with machinery to allow optimum conifer development.

◆ **Peters, V.S., S.E. Macdonald, M.R.T. Dale. 2006.** Patterns of initial versus delayed regeneration of white spruce in boreal mixedwood succession. Can. J. For. Res. 36(6): 1597-1609.

Author abstract: The timing of white spruce regeneration in aspen (*Populus tremuloides* Michx.) – white spruce (*Picea glauca* (Moench) Voss) boreal mixedwood stands is an important factor in stand development. We examined boreal mixedwood stands representing a 59-year period of time since fire and determined (1) whether and when a delayed regeneration period of white spruce occurred, (2) whether the relative abundance of initial (<20 years) versus delayed (≥20 years postfire) regeneration is related to seed availability at the time of the fire,

and (3) what are the important regeneration substrates for initial versus delayed regeneration. Initial regeneration occurred primarily on mineral soil or humus, while delayed regeneration established primarily on logs and peaked 38–44 years after fire. Of the 20 stands investigated, seven were dominated by initial regeneration, six were dominated by delayed regeneration, and seven were even mixtures of both. The dominance of a site by initial or delayed regeneration could not be simply explained by burn timing relative to mast years or distance to seed source; our results suggested that fire severity and the competitive influence of initial regeneration on delayed regeneration were important at fine scales. Based on our results we describe several possible postfire successional pathways for boreal mixedwood forests.

◆ **Putman, William E. and Zasada, John C. 1986.** Direct seeding techniques to regenerate white spruce in interior Alaska. Canadian Journal of Forest Research, 16: 660-664.

Author abstract. Direct seeding techniques for regenerating white spruce (Picea glauca (Moench) Voss) were tested on 12 logged areas near Fairbanks, AK. Techniques examined included spot seeding on scarified seed spots with and without plastic cone shelters and spot seeding on nonscarified seed spots with and without plastic funnel shelters, all at three sowing times. After the second growing season, scarified treatments produced greater seedling survival. Cone shelters usually produced greater survival than unsheltered seeding on scarified seed spots and funnel shelters usually produced greater survival than unsheltered seeding on non-scarified seed spots. Sowing time had little effect on survival.

◆ **Putman, W.E. 1986.** Togotthele Lands 1984 Regeneration survey. Tanana Chiefs Conference Unpubl. Report.38 pp.

Compiler abstract. In 1984, the Tanana Chiefs Conference, Inc., Bureau of Indian Affairs, and Toghotthele Corporation, completed a forest regeneration survey on Toghotthele Corp. lands. The lands surveyed had been logged under contracts administered by the State of Alaska prior to conveyance of the land to the Toghotthele Corp. Portions of some harvest units were planted with white spruce one to five years prior to the surveys. The report documents regeneration on cutover areas, and makes recommendations for future management. The report assumes that white spruce is the favored crop tree, and that management will aim to establish white spruce in harvested areas. Overall, all units were adequately stocked with acceptable tree species (birch, aspen, balsam poplar, and white spruce). White spruce was present on 53% of the stocked plots.

◆ **Sanders, R.C. 2003.** Summary of reforestation on Tyonek Village lands harvested by Gates Construction 1999 to 2003. Unpublished. 14 pp.

Compiler abstract: This study was done to prepare a status summary of tree regeneration and areas that will benefit from mechanical scarification on recently harvested tracts. Harvests were partial cuts of white spruce during a spruce bark beetle outbreak.

◆ **Sprankle, J. and W. Putman. 2002.** Reforestation survey report of State of Alaska timber sales in the vicinity of Cummings Road. Unpubl. Report by Tanana Chiefs Conf. for State of Alaska, DNR Division of Forestry. 36 pp.

Compiler abstract. In early June 2002, forestry staff at Tanana Chiefs Conference, Inc. (TCC) conducted a reforestation survey of several harvested site on state land in the Delta Area. These surveys were targeted to include the lowest known stocked harvest units in the management area. Intensive surveys were conducted on six units within two sales. In addition, extensive evaluations were done on multiple units in eight sales where successful regeneration was obvious. The intensive surveys assessed stocking levels and quality. The six units surveyed ranged from 70% to fully stocked. The authors reported that all the units in the extensive evaluations were satisfactorily stocked with white spruce and /or hardwood reproduction. Most units were overstocked and several would benefit from pre-commercial thinning. Most units also had a significant amount of residuals saplings, poletimber, and sawtimber that was not harvested during logging operations. Some larger residual trees were damaged from felling and skidding operations. These trees do not necessarily add to the health of the future stand but add benefits for wildlife.

◆ **Timothy, C. 1990.** Effect of vegetation competition on tree seedling establishment and growth in an upland, post-fire succession in Interior Alaska. Unpubl. M.S. Thesis. Univ. of Alaska Fairbanks. 48 pp.

Checking for abstract with Celia

◆ **Tousignant, D. 1995.** Effect of tree flowering and crown position on rooting success of cuttings from 9-year-old black spruce of seedling origin . C.J.F.R. 1995, 25 (7) 1058-1063.

Author abstract. Cuttings were taken at different levels in the crown of both flower-bearing and sexually immature 9-year-old black spruce seedlings (*Picea mariana* (Mill.) B.S.P.). We obtained satisfactory rooting success, despite the relatively old age of the trees. The rooting percentage of the cuttings taken from the lower third of the crown was significantly higher ($p < 0.01$) than that of the cuttings originating from the middle and top thirds of the crown (53%, 36%, and 29%, respectively). Cuttings from the upper portion of the crown showed persistent signs of advanced maturation, while those from the bottom of the crown regained an almost juvenile appearance after rooting. Surprisingly, the cuttings taken on flower-bearing trees rooted better ($p < 0.10$) than those taken on sexually immature trees (48% vs. 30%). Large and significant differences were also recorded between individuals of both groups. No significant interaction was found between sexual maturity and crown position of the cuttings for rooting percentage. The effects of maturation on the rate of rooting and the relevance of replacing grafting by rooting for certain purposes are discussed.

◆ **van Hees, Willem W.S. 2005.** Spruce reproduction dynamics on Alaska's Kenai Peninsula, 1987-2000. Research Paper PNW-RP-563. Portland, Oregon: USDA Forest Service, Pacific Northwest Research Station. 18 p.

Author abstract: During the past 30 years, spruce forests of Alaska's Kenai Peninsula have undergone dramatic changes resulting from widespread spruce bark beetle (*Dendroctonus rufipennis* (Kirby)) infestation. In 1987 and again in 2000, the Pacific Northwest Research Station's Forest Inventory and Analysis Program conducted initial and remeasurement inventories to assess broad-scale impacts of this infestation.

Changes in regeneration of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and white spruce (*Picea glauca* (Moench) Voss) are examined by using data collected on 130 plots. Regeneration of Sitka and white spruce in terms of mean number of seedlings per plot is not significantly different from the 1987 findings. The number of plots where seedling stocking remained at previous levels or increased, slightly exceeded the number of locations where seedling stocking declined. Almost half the plots (49 percent) had decreased numbers of seedlings, and almost 72 percent of the plots fell in the less-than-fully-stocked category in both inventories. Also, the distribution of the seedlings over the plot was not uniform. No plots had seedlings on all plot cluster sample points in either inventory.

◆ **Wahrenbrock, W. 2014.** Reforestation techniques. Unpubl. E-mail from Wade Wahrenbrock (Kenai Pen. Borough) to Hans Rinke (AK Div. of Forestry), May 13, 2014. 1 p. + photos.

Compiler note. Wahrenbrock visited a tract of state land near Anchor Point that were salvage logged in about 2000-2002. After logging, the site was dominated by *Calamagrostis* with almost no natural regeneration of trees. In 2012, under the Kenai Peninsula Borough spruce bark beetle mitigation program the site was treated with mastication and about 250 trees per acre were planted. Survival seems very good; probably around 95%. The trees happened to be planted when the rabbit/hare population was hitting a peak. Rabbits munched on many of the planted trees but they killed very few --- just set back the growth production. Natural regeneration is not doing quite as well as expected. Overall, the techniques used in the form of masticate site prep and tree planting are proving successful on grass dominated sites. Wahrenbrock also plans to visit the Caribou Hills area where mounding style site prep was used to compare the treatments.

◆ **Wurtz, T.L. 2000.** Interactions between white spruce and shrubby alders at three boreal forest sites in Alaska. PNW-GTR-481. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 29 p. (available on the web at http://www.fs.fed.us/pnw/pubs/gtr481.pdf)

Author abstract. To document possible soil nitrogen mosaics before timber harvesting on three boreal forest sites in Alaska, maps of the distribution of understory green (Alnus crispa (Ait.) Pursh) and Sitka alder (A. sitchensis (Reg.) Rydb.) stems were made. Understory alders were regularly distributed throughout the northernmost site (Standard Creek) and very irregularly distributed at the southernmost site (Cooper Landing). No consistent relations existed between alder stem location and total soil nitrogen. In undisturbed forest, soils

collected beneath alders tended to have more nitrogen than soils without alder, but after the sites were harvested, soil chemistry differed. To examine the interactions of alder and white spruce (Picea glauca (Moench) Voss) on secondary successional sites, mixed plantations of white spruce and alder were established after each site was harvested. Despite good survival, the planted alder grew poorly. No differences were found between nursery-grown alder seedlings and alder wildlings in either growth or survival. Although fifth-year survival and growth of white spruce were
excellent on all sites, they were not related to either the preharvest distribution of naturally occurring alder or to alders planted in the mixed plantations. Locational information and site maps are provided for future evaluation of these plantations.

◆ **Wurtz, T.L., Zasada, J.C., 2001.** An alternative to clear-cutting in the boreal forest of Alaska: a 27-year study of regeneration after shelterwood harvesting. Can. J. For. Res.-Rev. Can. Rech. For. 31, 999-1011.

Author abstract. We present 27-year results from a comparison of clear-cutting and shelterwood harvesting in the boreal forest of Alaska. Three patch clear-cut and three shelterwood units were harvested in 1972; about 100 dispersed white spruce (Picea glauca (Moench) Voss) leave trees per hectare were retained in the shelterwoods. Units were mechanically scarified and an exceptionally large seed-crop was dispersed that year. Shelterwood trees were removed after 15 years. After 27 years, overstory treatment had no effect on the density or growth of the species we studied, while scarification had highly significant effects. In 1999, scarified areas were densely populated with white spruce seedlings and saplings (118 000 - 129 000 stems/ha, with spruce in 100% of plots). Unscarified areas had far fewer spruce stems but were nevertheless well stocked (11 000 - 15 000 stems/ha, with 87% frequency). Initially, spruce grew best on scarified surfaces, but by 27 years, growth of the tallest spruce saplings was significantly greater on unscarified than scarified surfaces. By 27 years, cover of the grass Calamagrostis canadensis (Michx.) Nutt. had returned to preharvest levels in all treatment types. Because criteria for evaluating forest management practices have changed since this study was begun, partial overstory retention systems for the management of Alaska's boreal forest deserve further study.

◆ **Youngblood, A., and T. A. Max. 1992.** Dispersal of white spruce seed on Willow Island in interior Alaska. Portland, Or. : U.S. Dept. of Agriculture, Forest Service, Pacific Northwest Research Station. RP-443. 17 pp.

Author abstract. The seasonal and spatial patterns of dispersal of white spruce (Picea glauca (Moench) Voss) seed were studied from 1986 to 1989 in floodplain stands along the Tanana River near Fairbanks, Alaska. Analysis of the 1987 crop showed that production of filled seed was strongly related to estimated production of total seed and unrelated to selected stand structural characteristics. A mathematical expression, developed to estimate dispersal of filled seed into clearcut openings, predicted dispersal between 10 and 120 meters from the edge of an opening. The pattern of wind during the seed-dispersal season was predictable and consistent with winds measured at the Fairbanks Intemati0nal Airport. The results give forest managers ways to increase natural regeneration of white spruce in interior Alaska.

◆ **Youngblood, A.P. 1990.** Effect of shelterwood removal methods on established regeneration in an Alaska white spruce stand . CJFR 20(9): 1378-1381.

Author abstract. Seedling damage during overstory removal was compared among different yarding methods; almost three times more mortality was associated with rubber-tired ground skidding than with skyline cable yarding. Seedlings ranging in height from 0.4 to 1.0 m generally received less damage or had lower mortality rates from cable yarding than did shorter or taller seedlings. Snowpack disturbance and percentage of seedling mortality were positively correlated. Results suggested that with attention to seedling height growth and yarding method, the shelterwood regeneration system is a viable option for white spruce (*Picea glauca* (Moench) Voss) stand regeneration in interior Alaska.

◆ **Youngblood, A.P. and J.C. Zasada. 1991.** White spruce artificial regeneration options on river floodplains in interior Alaska. Canadian Journal of Forest Research, 21: 423-433.

Author abstract. Reforestation options for artificial regeneration of white spruce (Picea glauca (Moench) Voss) were tested on three floodplain sites near Fairbanks, Alaska. Survival of containerized seedlings after outplanting was above 96%, regardless of harvest cutting method or mechanical site preparation, and declined little between the third and fifth growing seasons. Establishment and survival after direct seeding on seed spots was more variable and differed by harvest cutting method, by type of site preparation, and by the use of plastic seed shelters for seedling protection. Maximum terminal leader growth, seedling total height, and basal diameter were found on planted seedlings in clear-cut units on the better site. In clear-cut units prepared by blading on one site, basal diameter of seedlings five seasons after outplanting was almost 50% more than on similar surfaces in shelterwood units. Planted seedlings on unscarified surfaces and in small scalped patches generally had similar basal diameters. Results suggested that similar interior Alaska floodplain forests of white spruce can be successfully regenerated by using the clear-cutting harvest method and planting nursery-reared seedlings without mechanical site preparation.

◆ **Zasada, J.C. 1990.** Developing Silvicultural Alternatives for the Boreal Forest – An Alaskan Perspective on Regeneration of White Spruce. *USDA Forest Service Forest Industry Lecture Series Lecture No. 25*. 44p.

Author abstract. The boreal forest is comprised of many conifer and hardwood species. One of the more difficult forest management concerns has been the regeneration of white spruce (Picea glauca) following harvesting of the extensive mixed conifer and mixed conifer-hardwood stands located in western Canada and Alaska. This paper generally describes research conducted in Alaska over about a 20-year period regarding the regeneration of white spruce and the development and testing of alternatives for natural and artificial regeneration

◆ **Zasada, J.C., 1986**. Natural regeneration of trees and tall shrubs on forest sites in interior Alaska, in: Van Cleve, K., Chapin III, F.S., Flanagan, P.W., Viereck, L.A., Dyrness, C.T. (eds.), Forest Ecosystems in the Alaskan Taiga: A Synthesis of Structure and Function. Springer-Verlag, New York, New York, USA, pp. 44-73.

Author abstract. The forests of interior Alaska are used for a variety of consumptive and nonconsumptive uses. Multiple- or single-use management of these forests requires a working knowledge of how these uses affect the sustained yield or availability of a particular product or use. Many biotic and abiotic environmental variables as well as socio economic concerns must be considered in developing these management alternatives. A knowledge of the reproductive biology and ecology is a necessary component in this decision-making process. Sustained production has, as an absolute requirement, the ability of the land manager to predict or determine the consequences of any disturbance in terms of the species composition and density; a detailed knowledge of the reproductive process is one important component necessary for developing this predictive capability. In many cases, it is possible for the land manager to create conditions that are more or less favorable for a selected species or group of species, and thus to exercise some control over the natural developmental process and pattern of forest types and distribution of trees within a type.

◆ **Zasada, J.C. 1978.** Case history of an excellent white spruce cone and seed crop in interior Alaska : cone and seed production, germination, and seedling survival . USDA Forest Service Gen. Tech. Rep. PNW-65. 53 pp.

Author abstract. The development of the excellent crop of 1970 is described until 1975 in 29 stands and a transect along the Richardson Highway. Detailed observations of seedlings were made in a small forest opening of the Bonanza Creek Experimental Forest, and comparative data are given for paper birch (Betula papyrifera) in the same stand. Management implications are discussed.

◆ **Zasada, J.C. 1972.** Guidelines for obtaining natural regeneration of white spruce in Alaska USDA Forest Service PNW Forest and Range Exp. Sta. 17 pp. Portland, OR.

Author introduction. Harvesting of white spruce is currently being conducted on a limited scale in Alaska. At the present time no particular attempt is being made to regenerate these stands. However, there is a need to secure natural regeneration in these stands now and in those that will be harvested. This paper suggests a number of silvicultural treatments known to provide adequate conditions for the successful natural regeneration of white spruce and discusses some factors which must be considered in applying these treatments. The recommendations in this report are mainly the result of research conducted and experience gained in western Canada and of minimal Alaskan observations, primarily in the Tanana drainage. References to a particular subject can be found in Zasada and Gr egory (1969).

Land managers should consider these recommendations a first approximation in prescribing harvesting methods, silvicultural systems, and site preparation for interior Alaska conditions. The practices prescribed in these first harvesting operations and their results must be well documented. This will allow the land manager to critically evaluate these practices and to accumulate information for refinement of the recommendations.

Some basic considerations for all timber harvesting are:

1. No practices or techniques should be prescribed which unnecessarily degrade primary land values (e. g. , soil erosion and water quality and site productivity impairment).

2. Practices which minimize the danger to adjacent, unharvested forest stands should be prescribed (e. g. , large accumulations of slash and dead or dying trees, which could be breeding sites for insects and diseases as well as creating a fire hazard, should be eliminated).

3. Forest harvesting must be considered as a management tool for obtaining regeneration as well as for the removal of the mature forest crop.

The approach used in preparing these guidelines has been to present the basic recommendations in table form. This gives the land manager a ready reference to the recommended practices. In addition, there is a brief discussion of the rationale behind the recommendations, possible means of implementing some of them, and a list of selected references.

The basic assumptions made in preparing these guidelines were:

1. White spruce can be naturally regenerated following harvesting of mature stands. Provided there is a mineral soil or similar seedbed, it is believed that there are no limitations to natural regeneration of white spruce in this part of the taiga. However, at similar latitudes in northern Finland and Scandinavia, natural regeneration is sometimes difficult and long regeneration periods are required.

2. Natural regeneration is to be relied upon in reforesting harvested or otherwise disturbed area . Under current economic conditions, this assumption is valid. However, where natural regeneration is unreliable, artificial regeneration will be required.

◆ **Zasada, J.C. and Gregory, R.A. 1969.** Regeneration of white spruce with reference to interior Alaska: a literature review. USDA Forest Service, Pacific Northwest Forest Experiment Station Research Paper PNW-79.

Author abstract. This paper reviews literature concerning natural regeneration of white spruce in the southern boreal forest and incorporates what is known about this subject for the boreal forests of interior Alaska. A mineral soil seedbed; reduction of competing vegetation; shade, especially during the first growing season; and an adequate seed supply are the four main regeneration requirements. Absence of a mineral soil seedbed appears to be the critical factor in the southern spruce forests.

◆ **Zasada, J. C.; Slaughter, C.W.; Teutsch, C.E.; Argyle, J. D.; Hill, W. 1987.** Winter Logging on the Tanana River Flood Plain in Interior Alaska. *Northern Journal of Applied Forestry* 4(1) 11-16.

Author abstract. Flood plains in interior Alaska support an important forest resource. Silvicultural alternatives for these sites depend on access and on the effect of timber harvesting on the residual stand and site. Some aspects (i.e., road access, logging damage to residual stand, and effect of logging on snow pack) of winter logging of white spruce on an island in the

Tanana River were observed. Winter roads of snow and ice were easily developed over a variety of surface conditions and appeared to have little lasting impact. Damage to uniformly spaced residual shelterwood trees was variable. Much of this damage could be eliminated by better sale administration, methods of sale layout, and harvesting methods. Logging activity created two distinct snow layers--an upper layer mixed with logging debris and a lower, compacted layer that showed little evidence of being physically disturbed. The compacted layer could provide good physical protection to seedlings and protect the forest floor frown disturbance.

◆ **Zasada, J. C., L.A. Viereck, M.J. Foote, R.H. Parkenson, J.O. Wolff, L.A. Lankford Jr. 1981.** Natural regeneration of balsam poplar following harvesting in the Susitna Valley, Alaska. For. Chron. 57: 57-65.

Author abstract. Regeneration of balsam poplar was studied following clearcut logging with both chain saws and tractor-mounted shears in summer and winter. Logging with shears in both summer and fall resulted in the most surface disturbance and the greatest rate of poplar regeneration. Stocking averaged 29% (range 4-62%) 4 years after harvesting. Regeneration was from seeds, stump sprouts, root suckers, and buried branches. Regeneration in summer-and winter-logged sites was primarily from root suckers, but logging in the fall resulted in regeneration from buried branches. More than 50% of the stumps produced sprouts the 1st and 2d years; but after 4 years, only 15% of the stumps in the areas logged in summer still had live sprouts. Revegetation of clearcut areas was rapid and dominated by grasses, horsetails, willows, alders, and devil's club. Production of moose browse was much greater in the logged areas than in an unlogged control. Limiting clearcutting to summer and encouraging disturbance of the surface could increase poplar regeneration.

SOILS AND SITE PREPARATION

◆ **Arikian, M.J., K.J. Peuttmann, A.L. Davis, G.E. Host, George E., J. Zasada. 1999.** Harvesting Impacts on Soil Properties and Tree Regeneration in Pure and Mixed Aspen Stands. Conference Proceedings. p. 329-331

Author abstract. Impacts of clearcutting and selective harvesting on pure aspen/mixed aspen hardwood stands were examined in northern Minnesota. We studied these impacts on 18 stands, which were harvested 4 to 11 years ago and received no further treatment. In each stand, residual composition, soil compaction, and tree regeneration were determined along a gradient of disturbance in the summer of 1998. This preliminary assessment investigates interacting effects of soil compaction, residual overstory conditions, and timing of harvests. Compaction levels were much more variable in areas that were harvested in summer rather than in winter. Stands harvested in the winter were associated with higher regeneration stem densities and height growth than those harvested in the summer. Tree regeneration stem densities and height growth decreased with increasing soil compaction and increasing residual basal area. These results show the importance of understanding complex interactions between pre-harvest and post-harvest conditions, harvesting disturbance, and soil properties as they determine future stand composition and productivity.

◆ **Bella, E.M., 2013.** *Calamagrostis Canadensis* treatment plots vegetation summary. Unpublished report.

Author abstract. Vegetation cover and structure was measured in five plots in each of three bluejoint reedgrass (*Calamagrostis canadensis* L.) treatment plot sites (Griner, Mile 149, Kenai) on the western Kenai Peninsula on August 1st, 2013. Plots were circular one meter area plots, set up with a center stake and a measured flexible string perimeter. The purpose was to assess effectiveness of bluejoint reedgrass control types by examining general vegetation composition within each of the five different treatments (weed whacker, T1; mower, T2, masticate, T3, herbicide, T9; and herbicide & burn, T12) and to potentially detect any differences in vegetation composition and structure between treatments and sites. Percent of ground cover was measured within each plot, in five categories. Percent by life form and percent cover by species was also measured within each plot, and are referred to as environmental parameters.

◆ **Boateng, J.O., J.L. Heineman, L. Bedford, G. J. Harper, and A.F.L. Nemec. 2009.** Long-term effects of site preparation and postplanting vegetation control on Picea glauca survival, growth and predicted yield in boreal British Columbia. Scandinavian Journal of Forest Research 24:111-129.

Author abstract. The 19-20 year effects of mechanical site preparation, windrow burning, chemical site preparation, and post planting vegetation control on survival and growth of planted white spruce are reported from two boreal sites in British Columbia, Canada. Survival differed between treatments at both sites, but was relatively good (≥77%) even in untreated plots. Current data regarding the proportion of spruce that were physically overtopped by vegetation and previous results from related soils and vegetation studies suggest that lasting reductions in tall shrub and aspen abundance were more important to spruce growth than early micro-environmental effects associated with manipulating the rooting environment. At Inga Lake, post planting vegetation control produced a 13-fold increase in spruce volume over the control after 19 years, which was statistically equivalent to increases resulting from fine mixing, plow-inverting and windrow burning site preparation treatments. At Iron Creek, chemical site preparation and plow-inverting quadrupled spruce volume, whereas mounding, patch scarification and disc trenching were ineffective. Growth and yield simulations using treatment-specific site index curves for Inga Lake suggested that rotation length could be shortened by 12-16 years through the use of site preparation or post planting vegetation control. However, untreated areas, due to the relatively good survival of white spruce at age 19, were predicted to produce equivalent volume if left to grow to mean annual increment culmination age.

◆ **Boateng, J.O., J.L. Heineman, J. McClarnon, and L. Bedford. 2006.** Twenty year responses of white spruce to mechanical site preparation and early chemical release in the boreal region of northeastern British Columbia. Canadian Journal of Forest Research, 36: 2386-2399.

Author abstract. The effects of six mechanical site preparation treatments, two stock-type treatments, and early chemical release on survival and growth of planted white spruce (*Picea glauca* (Moench) Voss) were studied in the BWBSmw1 biogeoclimatic zone of northeastern British Columbia. After 20 years, spruce height and diameter were larger in all mounding treatments than in the control. Early results suggested better spruce performance on large than small mounds, but after 20 years, growth was equally good on small mounds as on mounds with 20 cm mineral capping. Spruce planted on hinge positions in the Bräcke patch and blade scarification treatments did not survive or grow well. Early chemical release improved spruce growth equally as well as the mounding treatments. Twenty year spruce survival averaged 71% in the 14 and 20 cm mound treatments, 60% in the early chemical release treatment, and ≤35% in the Bräcke patch and blade scarification treatments. A large stock type was also planted in untreated ground and, after 20 years, had similar survival and growth as the standard stock type. Differences in survival had a large effect on basal area at age 20 years. Trend analysis showed that treatments diverged into two distinct groups with regard to spruce size during the 20 year span of the study.

◆ **Crossley, D.I. 1955.** Survival of white spruce reproduction resulting from various methods of forest soil scarification. 1955. Crossley, D.I. Government of Canada, Department of Northern Affairs and National Resources, Forestry Branch. Forest Research Division Technical Note 10. 10 pp.

Author summary. A study was undertaken on the Kananaskis Forest Experiment Station, Alberta, to investigate the effect of fire and of certain mechanical equipment in the preparation of seed-beds receptive to white spruce reproduction on inadequately restocked cut-over areas. Soils were scarified by 11 different methods during the summer of 1948. An initial report based on two years data was prepared and published (Crossley, 1952). The present publication is based on three years additional data, and reports that all methods of soil treatment under study have proven more effective than the untouched control, that several of them satisfy even the most demanding stocking requirements, and that certain degrees of improved receptivity are still evident five years after treatment. In addition it is apparent that loss of seed prior to germination is a factor of major importance, and that seed crop evaluation is intimately connected with choice of seed-bed treatment. The investigation will continue.

◆ **Dyrness, C. T., L.A. Viereck, M.J. Foote, J.C. Zasada. 1988.** The Effect on vegetation and soil temperature of logging flood-plain white spruce . USDA Forest Service Res. Pap. PNW-RP-392. Portland, OR. 51 pp.

Author abstract. During winter 1982-83, five silvicultural treatments were applied on Willow Island (near Fairbanks, Alaska): two types of shelterwood cuttings, a clearcutting, a clearcutting with broadcast slash burning, and a thinning. The effects of these treatments on vegetation, soil temperature, and frost depth were followed from 1983 through 1985. In 1984 and 1985, logged plots had significantly higher soil temperatures than did the controls; clearcut and burned sites had the greatest increases. Vegetation composition was profoundly changed on the clearcut and burned units and altered to a lesser extent on the units receiving the other treatments.

◆ **Gingras, J.-F. 1990.** Harvesting methods favouring the protection of advance regeneration: Quebec experience. Forest Engineering Research Inst. of Canada. Tech. Note. TN-144. 8 pp.

Author abstract. This report examines the use of several harvesting systems which can favour the protection of advance regeneration already established on the site before harvesting takes place. The methods studied were modified systems using a feller-buncher with a cable of a clambunk skidder, feller-forwarders, single-grip harvesters with a forwarder, and a prototype feller-delimber. The advantages, disadvantages, and relative efficiency in protecting the regeneration using the different methods are discussed.

◆ **Hunt, J. A. 1988.** Mechanical site preparation and forest regeneration in Sweden and Finland: implications for technology transfer . Canadian For. Service. FRDA Report, Volume 26, Issue 3.

Author abstract. Swedish and Finnish (Fennoscandian) mechanical site preparation experience is extensive. An understanding of its evolution should benefit development of site preparation in Canada. Since site preparation is just one component of forest regeneration, which in turn is integrally related to the whole process of forest management, a technical study of site preparation was thought to be insufficient without some discussion of silviculture in Fennoscandia. This report, therefore, describes some trends in Fennoscandian silviculture, and mechanical site preparation and reforestation techniques. Implications for the transfer of this technology to British Columbia are also discussed.

◆ **Lees, J.C. 1963.** Partial cutting with scarification in Alberta spruce-aspen stands. Ottawa, [Ont.]: Dept. of Forestry, Forest Research Branch, 1963. Dept. of Forestry publication ; no. 1001

Need abstract *checking with Celia*

◆ **Lieffers, V. J. and S. E. Macdonald**. **1993.** Ecology of and control strategies for *Calamagrostis canadensis* in boreal forest sites. Canadian Journal of Forest Research 23: 2070-2077

Author abstract: *Calamagrostis canadensis* (Michx.) Beauv. Is a widely distributed rhizomatous grass that can seriously inhibit growth of white spruce (Picea glauca (Moench) Voss) seedlings in the boreal forests of North America. We review the dynamics of this grass during four successional stages: the colonization of disturbed sites; dominance of the site by the grass a few years after disturbance; gradual loss of dominance with overstory development; and maintenance of the grass at low levels in the understory of mature forest. We also describe *C. Canadensis* in relation to recruitment from clonal growth and seed environmental conditions for growth, the effects of grass litter buildup on conifer seedling microclimate, and overall competitive abilities. Control strategies for *C. Canadensis* are as follows. If the grass is found in nearly every square meter in the understory prior to logging, there will be rapid spread when the stand is clear-cut unless clones are killed using herbicides or a deep burn. Large spruce seedlings, planted on large soils scalps or mounds, coupled with release by way of herbicides or sheep grazing, may be necessary for plantation establishment under conditions of encroachment by *C. Canadensis*. Alternatively, the shade provided by a partial canopy may inhibit the grass sufficiently to allow spurce seedlings to establish. If grass is not abundant in the understory, we recommend (i) minimizing forest floor disturbance to reduce sites for grass seedling colonization or (ii) a slash burn with the hope of encouraging colonization by herbaceous species that have less impact on conifer seedlings.

◆ **Lyon, N. F. 1977.** White spruce seed tree system with mechanical seedbed preparation . Ontario : Ministry of Natural Resources, Silvicultural Note #15. 15 pp.

Author introduction. Tree planting, to regenerate white spruce *(Picea glauca* (Moench) Voss) on harvested areas, is currently conventional but is expensive and not always successful. An alternative to plating for areas including in current cutting plans is a modified clearcut involving the leaving of white spruce seed trees combined with mechanical seedbed preparation. The system has been tried with varying degrees of success on a limited operational basis in a number of areas in northern Ontario. Significant gains in the white spruce content of 2000-9000 established stems per acre (approx. 4900-22,000 per hectare at stockings ranging from 55 to 85 percent have been obtained in research trials. On the net treatment portion of these trials densities over the range of 4000-15,000 stems per acre (approx., 9800-37,000/ha) with stockings of 70 to 95 percent were obtained (Lyon 1968). In one specialized forest management area where the objective was to create a natural white spruce seed production area by applying some of the principles of the seed tree system, densities in excess of 10,000 stems per acres (approx. 25,000.ha) were obtained (Skeates 1961, Jovic 1972).

The seed tree system demands more advanced planning, field inspection and procedural consideration s than do the conventional reforestation techniques. Before harvesting, the soil and stand characteristics must be examined to determine the suitability of the area for the system. The seed trees must be carefully selected and reserved from cutting. A seed year must be ascertained before seedbed preparation is carried out. The seedbed treatment must be carried out iin advance of seed fall.

While the success of the system is directly related to a number of interlocking factors its fundamental consideration is that if there is no natural white spruce seed source left on the harvested area then there will be no additional natural white spruce regeneration.

The success of the system is also based on the need for the forest manager to have a known or desired forest objective, i.e., a predetermined visualization of the white spruce component in the forest wanted. The objective must be established by prior consideration of the whole range of management and species working group objectives and regeneration alternatives available.

This silvicultural note is intended as a short summary of the most important facets for using this regeneration system. The recommendations are based on observations and experience obtained in operational trials as well as on reviews of pertinent literature. As described here the system is designed and recommended as a post-harvest regeneration treatment provided that the necessary pre-harvest reservations have been made. If necessary and with some modifications, particularly in machine size and manoeuverability and in some aspects of competition control, the system could be undertaken as a pre-harvest regeneration system.

It is planned that his note be amended as and where additional information is obtained from more operational usage of the system.

◆ **Macey, D.E. and R. S. Winder. 2001.** Biological Control and the Management of *Calamagrostis canadensis* (Bluejoint Grass). Canadian Forest Service, Forestry Research Applications, Pacific Forestry Center. Technology Transfer Note 25. 6 pp.

Compiler abstract. This article reviews control options for *Calamagrostis canadensis* following harvest. It briefly summarizes pros and cons of chemical herbicides, prescribed burning, mechanical site preparation, manual grass cutting, sheep grazing, and mulch mats. The authors note that practices that reduce grass growth are often preferable to eradication, and they discuss planting herbaceous plants that compete with grass, conducting partial harvests, planting larger tree seedlings, and increasing stocking densities. The article covers biological control options in more depth, including research on fungal pathogens, deleterious rhizosphere bacteria (DRB), and combinations of the two. In greenhouse tests, both pathogens and DRB showed promise for reducing grass competition, but were most effective used in combination. These treatments did not cause foliar or root damage nor affect growth of white spruce, lodgepole pine, or trembling aspen seedlings.

The authors state that it is important for forest managers to recognize the threat of *C. canadensis* invasion prior to harvest, and incorporate practices that minimize invasions and control grass spread into silvicultural prescriptions. Partial cutting could reduce the risk of serious infestation. Practices that mix the soil encourage grass rhizome sprouting and germination of buried seed, as does light burning. Immediate planting following disturbance using large caliper stock and higher than minimum stocking densities is a major defense against infestation.

Although no biologicals are currently registered for use in forestry, an integrated strategy that combines biological control with low-impact silvicultural techniques is envisioned. A strategy to proactively control infestations before they begin will be most successful at reducing plantation failure and increasing tree productivity in areas of high risk for grass invasion.

◆ **Maini, J. S. and K.W. Horton. 1966.** Reproductive response of Populus and associated Pteridium to cutting, burning and scarification . Canada. Dept. of Forestry and Rural Development) ; no. 1155.

Introduction. *Populus tremuloides* Michx. And *P. grandidentata* Michx. (aspens), taxonomically and silviculturally closely related species, are gaining economic importance in North America. Whereas natural regeneration of these two species is negligible in undisturbed stands, abundant root suckering generally occurs when aspen stands are subjected to cutting, burning and other disturbances. According to Main (1960) and Maini and Horton (1966) an insolation-induced thermal increase usually plays a critical role in sucker initiation. Management of aspen stands, either for the propagation of aspen or for conversion to some other desirable species required judicious application of various cultural treatments. The present investigation was conducted during 1962 in southern Ontario to appraise the relative effects of cutting, burning and ground scarification treatments on the regeneration of *P. tremuloides, P. grandidentata* and associated ground vegetation , particularly *Pteridium aquilinum* (L.) Kuhn (bracken). The influence of these treatments on the heat economic the upper soil layers was also evaluated.

The significance in the timing of cutting aspen stands has been discussed by Baker (1918) and Stoeckeler and Macon (1956). Dormant-season cutting produces initially more vigorous toot sucker regeneration than summer cutting because in the latter, suckers emerge when the reserve food material in the roots is presumably low and competition by associated ground vegetation is intensive. The later the suckers appear during the growing season, the poorer is their development. However, after a lapse of two years, sucker density was similar in summer-cut and winter-cut stands (Sandberg and Schneider 1953).

Scarification by discing has been found effective for inducing aspen suckering in under-stocked stands (Zillgitt 1951) and in stands where cull trees have been left standing (Zehngraff 1949). Also, following fire in a *Populus* stand, development of a dense sucker crop is usual. An increase in number and vigour of suckers was observed when heavily cut areas were lightly burnt (Shirley 1931, 1932). Repeated burning also stimulated suckering (Shirley 1941).

*Suckering response of as*pen to the above cultural treatments is effected internally or externally, and it is impossible to separate the two. Among the internal influences, sucker formation may result from injuries inflicted on stems and roots by cutting, scarification or burning, which upset the internal metabolic balance. However, the same disturbances have important external effects—the thermal, hydrological and nutrient conditions may be significantly altered by removing trees, ground vegetation and loose litter, by burning organic matter, as well as by disturbing and loosening superficial soil layers. The present study attempts to separate these causative factors and to determine their relative effects on reproduction of aspen and associated bracken.

◆ **Marquis, D.A. and J.C. Bjorkbom. 1960.** How much scarification from summer logging. USDA Forest Service, Northeastern Forest Exp. Sta. Forest Research Note NE-110. Upper Darby, PA.

Author abstract. Scarification of the soil creates seedbeds that are favorable for the establishment of both paper birch and yellow birch. Logging in the summer often has been recommended as a method of obtaining these seedbeds. However, our observations on experimental logging jobs have shown that logging alone does not provide scarification over enough of the area to assure reasonably uniform distribution of birch regeneration.

◆ **Newton, M. 1997.** Reforestation and vegetation in central Alaska. U.S. Dept. of Agriculture, Forest Service, Alaska Region, 1997. Special report R-10-TP. 80 pp.

Author summary. The three following papers summarize nine years of research of Oregon State University, Department of Forest Science relating to the principal technical obstacles to artificial regeneration in south-central and interior Alaska. The key elements include 1) determination of severity of plant competition and consequences of not weeding in the first five years of spruce plantations, 2) comparisons of methods of controlling competition, and 3) evaluation of environmental impacts of the various methods of vegetation control. We also address preliminary findings on importance of the size of planting stock after various forms of mechanical and chemical site preparation.

Plant competition in the forms of grass, fireweed, aspen, and other overtopping species severely reduces growth and survival of interior white spruce. Allowing vegetation to become established before planting leads to sharply poorer post-planting performance expressed as volume growth. Trees planted in established cover that is chemically controlled grow significantly more slowly than when planted in new clearcuts receiving apparently analogous degree of control. That is, it takes less cover to slow spruce growth in a 3-yer-old clearcut than in a new unit when all other conditions are the same. Seedlings grow twice as fast in the new clearcut than the old in the same ranges of cover. If the clearcut is freshly burned, seedlings grew twice as rapidly as in the new, unburned soil, cover for cover. In all types of harvest unit, speed of overcoming white spruce “planting check” was positively related to degree of freedom from competing cover. With competition–free plantings, height growth was approaching the same rate for all three types of unite (burned, new clearcut, 3-year-old cut), but methods of weeding other than annual chemical maintenance varied in efficacy according to weed cover at the time of planting; more cover reduced efficacy in general. This was observed near Fairbanks and also at Ft. Richardson. Patterns were very consistent for the two sites and different years of planting.

Mortality of planted spruce was affected principally by two factors. Overtopping was a major cause but often required several years to cause death. Very early several freezing (15° Sept. 8, 1993) caused mortality on Fairbanks experiments that were nearly competition-free, and were late-flushing. That was an extreme event, repetition of which is very rare, hence we discount freezing as a major risk of weeding.

Paper birch plantings responded to competition much as did white spruce. Unlike spruce, browsing by moose at Ft. Richardson all but eliminated differences in heights for various levels of competition, but weed-free birch developed much more stem volume and biomass. Freezing damage is a major cause of mortality in all treatments on sites with cold-air drainage.

When comparisons of planting stock types were done after four different methods of site preparation, plug-1 transplants were 2-4 times as large in year 3 as either of two commercial 1-0 plug types on sites treated with glyphosate plus hexazinone before planting. This site prep method was significantly more effective than spot spraying, mechanical clearing, or fresh logging alone. In all methods of site preparation, the plug-1's grew 2-4 times faster in terms of absolute growth than other stock types by year 3.

Efficacy of methods for controlling vegetation to meet seedling needs is very similar to findings in the Douglas-fir region. Glyphosate, imazapyr, and triclopyr may be used at rates that cause negligible harm to spruce, yet will kill most herbs and deciduous shrubs at chemical cost of <$50/ac plu application. Glyphosate is effective on most of Alaska's competitors for <$30/ac alone, but has no residual effect. Hand scalping and hand brushing may provide for confer establishment in grass or alder cover, but hand scalping of grass was difficult. Mechanical methods are feasible for favoring moose browse. Details of all treatments are given.

Environmental impacts of chemical methods were evaluated in terms of persistence and mobility of chemical residues in vegetation and soils. Rrsidues in vegetation were completely dissipated for glyphosate, imazapyr, hexazinone, and triclopyr within one year on a coastal site (windy Bay), and triclopyr persisted slightly longer al low levels near Fairbanks. Mobility in soil was low, with no more than 30% of an initial deposit in the surface soil moving below 6". Persistence in Alaska was comparable to growing season environments in the lower 48 states. Half-lives in the summer environments range from estimates of 25 to 120 days for the four products, with hexazinone the only one over about 50 days. No dissipation occurred or was expected in winter. All products were non-detectable by 410 days after treatment in all locations.

All four products evaluated are low in toxicity, and difficult of impossible to dislodge from the field environment unless freshly treated vegetation is contacted. Vegetation residues were all within the range of concentration producing no observable effects in test animals. Hexazinone moved off-site in water on large plots treated for evaluation of worst-case conditions. Whereas 7% of the applied hexazinone appeared to have left these sites under intensive rain events, concentrations are unlikely to reach detectable quantities in fish-bearing streams in basins with 5% of the entire basin receiving treatment.

Mechanical or manual controls of vegetation have inherently higher environmental impacts than herbicides in terms of total energy use, total chemical use and potential for causing stream pollution with silt or fuel. They also seldom provide extended control of vegetation in sufficient degrees to enhance over-all reforestation efforts at acceptable costs.

◆ **Norman, C.M. 1978.** Ripper scarification: A silvicultural technique developed in northwestern Alberta. The Forestry Chronicle. 54(1): 15-19, 10.5558/tfc54015-1

Author abstract. There are currently several different scarification techniques being applied silviculturally in Alberta. All techniques are designed around a crawler tractor equipped with a front-mounted dozer or ripper blade. Although these techniques are effective on better drained sites, their efficiency is limited on wet or frozen ground.Summer is the most suitable time for general reforestation operations but is often a very poor time for good forest access and site operability in low wet areas.With these considerations in mind, North Canadan Forest Industries Limited, Grande Prairie, determined the most economical time to carry out its scarification would be in winter when access is best and winter logging is in full scale operation. A parallelogram ripper mounted on the rear of a suitably sized crawler tractor has proven to be best suited for this heavy work. Equipment was designed, modified and built for use on the parallelogram ripper.Three thousand acres (1200 hectares) have been treated to date at a very reasonable cost, many of these acres being virtually untreatable during the summer or winter by conventional means.

◆ **Packee, E. C. 1990.** White spruce regeneration on a blade-scarified Alaskan loess soil. Northern Journal of Applied Forestry 7:121-123.

Author abstract. Following hardwood removal from a mixed spruce-birch-aspen forest stand, portions of the stand were blade-scarified to encourage natural white spruce regeneration. Six years after treatment the number and height of white spruce seedlings were significantly greater on scarified than on unscarified plots. Whereas 100% of scarified sample plots contained five or more seedlings, 73% of unscarified plots contained no seedlings. Exposure of mineral soil and removal of grass competition are essential for the satisfactory natural regeneration of white spruce. Detailed regeneration surveys should not be considered for white spruce until seedlings are 15 cm tall, typically the fifth or sixth year after site preparation.

◆ **Richmond, A. and T. Malone. 1986.** Observed scarification rates and contract costs for the TTS-35 disc trencher in interior Alaska . Univ. of Alaska, Fairbanks. Agric. and Forestry Exp. Sta. Circular 53. 14 pp.

Author abstract. The regeneration of interior Alaska's commercial forest lands is mandated by Alaska's Forest Resources and Practices Act (1979). This act requires that regeneration be established adequate to ensure a sustained yield on forested lands from which the timber has been harvested. Post-logging regeneration efforts now are aimed at exposing mineral soil for the natural seeding of white spruce. Soil exposure has been accomplished by blade scarifying with a crawler tractor which provides large seed sites or by using a Bracke-type patch scarifier which produces small seed sites of about 2 ft2. Arlidge (1967) reports that larger seedbeds have greater regeneration success than smaller ones. Some researchers have found that the regeneration of the larger plots may be too successful, requiring weeding and precommercial thinning to bring stocking to satisfactory levels (Zasada and Grigal 1978). The Alaska Division of Forestry (DOF) has not been satisfied with the cost or effectiveness of either of these site-preparation practices.

◆ **Smith, G.K.M. 1988.** Site preparation in cold soils. Canadian Forest Industries. Sept. 1988: 32-34. Southam Business Publications, Don Mills, Ontario.

Compiler summary. This paper summarizes presentations from Canadian, Scandinavian, and US forestry researchers and practitioners. In summary, presenters agreed that root extension ceases and seedling growth slows down below a threshhold temperature, typically about 5°C. Specific effects differ among white and black spruce and jack pine. During spring planting operations, soil temperature can remain well below air temperature. Warm, loose soils provide drainage, promote root extension, and have high nutrient availability. Mounding site preparation works on certain sites because mounds capture and retain heat and allow root extension. Research on mounding is underway in Ontario and Michigan. Information is needed over a forest rotation to determine whether root systems adapt well to mounds and whether trees in mounds are susceptible to windthrow. Foresters and scientists agree that some type of site preparation to raise soil temperature is better than none. Skilled equipment operators are critical for successful mechanical scarification.

◆ **Wiensczyk, A., K. Swift, A. Morneault, N. Thiffault, K. Szuba, and F. W. Bell. 2011.** An overview of the efficacy of vegetation management alternatives for conifer regeneration in boreal forests. The Forestry Chronicle 87:175-200.

Author abstract. In this paper, we discuss the broad array of treatments that could be used to control competitive vegetation in conifer plantations in the boreal forests of Canada. We present vegetation management alternatives screened based on their treatment efficacy, which we defined as their ability to (a) control competitive vegetation and (b) not cause undue damage to conifer seedlings. The treatments reviewed range from pre-harvest (preventative) to post-plant release (reactive) treatments, and are organized into five categories: (i) silvicultural and harvest systems, (ii) physical treatments such as mechanical site preparation, cutting, girdling and mulching; (iii) thermal treatments such as prescribed fire and steaming; (iv) cultural treatments such as seedling culture, cover cropping, and grazing; and (v) chemical and biological spray treatments. We based our assessment of treatment efficacy on previous reviews, expert opinion, and published literature. We conclude on the need to further assess the effectiveness of forest vegetation management strategies in the context of multi-purpose plantations that consider ecological, social and silvicultural objectives.

◆ **Youngblood, A., E. Cole, and M. Newton. 2011.** Survival and growth response of white spruce stock types to site preparation in Alaska. Canadian Journal of Forest Research **41**:793-809.

Author abstract. To identify suitable methods for reforestation, we evaluated the interacting effects of past disturbance, stock types, and site preparation treatments on white spruce (Picea glauca (Moench) Voss) seedling survival and growth across a range of sites in Alaska. Replicated experiments were established in five regions. At each site, two complete installations differed in time since disturbance: “new” units were harvested immediately before spring planting and “old” units were harvested at least 3 years before planting. We compared mechanical scarification before planting, broadcast herbicide application during the fall before planting, and no site preparation with 1-year-old container-grown seedlings from two sources, 2-year-old bare-root transplants from two sources, and 3-year-old bare-root transplants. Seedlings were followed for 11 years on most sites. Based on meta-analyses, seedling survival increased 10% with herbicide application and 15% with mechanical scarification compared with no site preparation. Scarification and herbicide application increased seedling height by about 28% and 35%, respectively, and increased seedling volume by about 86% and 195%, respectively, compared with no site preparation. Soil temperature did not differ among site preparation methods after the first 7 years. Results suggest that white spruce stands may be successfully restored through a combination of vegetation control and use of quality planting stock.

FIRE AND REGENERATION

◆ **Bella, E. M. 2012.** Tree regeneration rates in post-fire and post-beetle affected stands on the Kenai Peninsula. Unpublished report. Sept. 27, 2012. 38 pp.

Author abstract: A number of competing landscape cover models have been employed to predict future vegetation and fire regime change on the Kenai Peninsula. Model scenarios provide guidance for managing for change, but lack allowance for novel change or predictions of novel assemblages. Understanding tree regeneration dynamics in a post-beetle kill, warming climate may facilitate a transition to including novel assemblages and change in subsequent modeling efforts. In order to better understand natural tree regeneration rates to inform predictions, vegetation and cover data were collected on 45 plots in 9 sites with varying disturbance history. Sites were selected to represent reference conditions, recent (<20 years) fire-affected stands, and fire- and spruce bark beetle-affected stands. Data collection took place on five plots per site, including both bluejoint reedgrass presence and absence. A Pearson's correlation examined relationships between predictive site parameters and vegetation cover. Relationships between quantitative site, regeneration, and composition variables were analyzed through a nonmetric multidimensional scaling ordination. A multi-response permutation procedure was applied to overall site and various categorical disturbance parameters to determine plot independence. Fire severity affected ground cover and vegetation composition, which in turn impacted regeneration rates for spruce and birch. Data for quaking aspen and cottonwood regeneration was limited, so conclusions on regeneration rates were uncertain. Contributing factors to regeneration rates for birch and spruce also included bluejoint reedgrass presence and distance to seed source. Additional factors such as aspect and browse had no clear effect. An expanded study would include detailed fire severity and browse information, and target specific sites to include data for all tree species of interest. Additionally, sites could be expanded to include a greater spectrum of disturbance effects, including post-fire fuel reduction treatments, specific fire severity areas, beetle-only (no fire) areas, and targeted bluejoint reedgrass presence and absence locations.

◆ **Berg, E., 2004a.** Windy Point burn provides food through, and for moose, hares. Kenai Peninsula Clarion. Refuge Notebook. Aug. 13, 2004.

Compiler abstract. Column describes natural regeneration ten years after the 1994 Windy Point burn. Berg describes "doghair-thick stands of birch saplings" and abundant habitat for moose and hares. The Windy Point fire was a 2,800-acre severe, mineral soil exposing fire. The prior forest was mature upland black spruce and thick peat moss. The article references data from permanent plots established in the burn area.

◆ **Berg, E., 2004b.** Blown down trees reveal secrets of the forest – past and future. Kenai Peninsula Clarion. Refuge Notebook. Aug. 30, 2002.

Compiler abstract. Column describes evidence of fires and nurse logs in tree throw pits and mounds following the 1990s spruce beetle outbreak and subsequent logging on the Kenai Peninsula. Berg reports that previous generations of trees in the study area germinated either on exposed mineral soil following rare, intense fires, or on nurse logs. The intensity of the 1990s beetle outbreak left few pole-sized trees for advanced regeneration. Where logging occurred, most of the dead trees that could blow down and become nurse logs were removed. Some natural regeneration was observed in areas where logging equipment exposed mineral soil. Berg states that the best chance for regeneration in logged areas is replanting, and noted good survival of white spruce and lodgepole pine nursery seedlings.

Berg, E.E. and R.S. Anderson. 2006. Fire history of white and Lutz spruce forests on the Kenai Peninsula, Alaska, over the last two millennia as determined from soil charcoal. For. Ecol. and Mgmt. 227: 275-283.

Author abstract. The presence of over 429,000 ha of forest with spruce (Picea spp.) recently killed by spruce beetles (Dendroctonus rufipennis) on the Kenai Peninsula has raised the specter of catastrophic wildfire. Dendrochronological evidence indicated that spruce beetle outbreaks occurred on average every 50 years in these forests. We used 121 radiocarbon-dated soil charcoal samples collected from throw mounds of recently blown over trees to reconstruct the regional fire history for the last ca. 2500 years and found no relation between fire activity and past spruce beetle outbreaks. Soil charcoal data suggest that upland forests of white (Picea glauca) and Lutz (Picea x lutzii) spruce have not on average burned for 600 years (time since-fire range 90 to _1500 years, at 22 sites) and that the mean fire interval was 400–600 years. It would thus appear that 10 or more spruce beetle outbreaks can occur for every cycle of fire in these forests. We caution, however, that a trend of warmer summers coupled with an increasing human population and associated sources of ignitions may create a greater fire risk in all fuel types than was present during the time period covered by our study. We suggest that forest management focus on creating fuel breaks between valued human infrastructure and all types of forest fuels, both green and dead.

◆ **Berg, E.E., R. S. Anderson, and A.D. De Volder. 2006.** Fire history of spruce forests on the Kenai Peninsula, Alaska, on scales of decades to millennia, using fire scars, soil charcoal and lake sediments. http://depts.washington.edu/nwfire/publication/Berg_et_al_2006.pdf

Author introduction and results. The Kenai Peninsula has two distinct fire regimes: a high frequency regime in black spruce (*Picea mariana*) and a low frequency regime in white (*P. glauca*) and Lutz (*Picea* x *lutzii*) spruce. We examined these fire regimes on three different time scales, and estimated the mean fire return intervals and variances.

Black spruce: We used 189 fire scars to date 10 fires from 1708 to 1898. Fire return intervals ranged from 18 to 166 years, with a mean fire return interval (MFI) of 79 ± 35 (SD) years. (De Volder 1999)

White/Lutz spruce: We used 121 radiocarbon-dated soil charcoal samples to estimate an MFI of 515 ± 355 (SD) years over the last 2500 years, at 22 sites. Charcoal older than 2500 years was excluded from the MFI calculation because of concern about long-term disintegration of charcoal fragments and consumption of older charcoal by more recent fires. Times-since-fire ranged from 90 to 1518 years, with a mean of 605 ± 413 (SD) years. (Berg and Anderson 2006)

Sedimentary charcoal: Charcoal was measured at 1-cm intervals to provide a 13,000 year record of fire activity at Paradox Lake. Fire frequency was lowest during the initial shrub tundra period with an MFI of 138 ± 65 years beginning 13,000 years before present (BP), increased after the arrival of birch, *Salix*, and *Populus* at 10,700 years BP to an MFI of 77 ± 49 years, and decreased slightly to an MFI of 81 ± 41 years after the arrival of white spruce at 8500 years BP. After black spruce arrived at 4500 years BP, fire activity declined to the present MFI value of 130 ± 60 years, presumably reflecting the onset of a cooler and wetter climate. (Anderson et al. in press) The 130-year MFI estimated from sedimentary charcoal at Paradox Lake is considerably shorter than the 515-year MFI estimated from soil charcoal samples distributed over the central and southern Kenai Peninsula. This difference may be in part due to black spruce near Paradox Lake, but is more likely due to the fact that a lake can potentially accumulate charcoal from many fires distributed over a large area, whereas a soil charcoal sample represents a single fire at a single point on the landscape. Similar discrepancies have been reported in other studies comparing these two quite different methods (reviewed in Berg and Anderson 2006).

◆ **Boucher, T. V. 2003.** Vegetation response to prescribed fire in the Kenai Mountains, Alaska. PNW-RP-554. USDA Forest Service, Pacific Northwest Research Station, Anchorage, AK. 67 pp.

Between 1977 and 1997, 4000 ha were burned to promote regeneration of tree and shrub species used for browse by moose (*Alces alces*) in the Kenai Mountains. Species composition was documented along burned and unburned transects at 17 prescribed burn sites. Relationships among initial vegetation composition, physical site characteristics, browse species abundance, and competitive herbaceous vegetation were examined to determine controls on browse species regeneration after prescribed burning. Browse species abundance after burning was inversely related to *Calamagrostis canadensis* Michx. Beauv. (bluejoint reedgrass) abundance prior to burning. *Calamagrostis canadensis* abundance was related to specific landscape characteristics. Depositional slopes, such as fluvial valley bottoms and toe slopes, often featured soils with deep, loamy surface horizons. Sites with these characteristics generally showed large increases in *C. canadensis* cover after prescribed burning, even when *C. canadensis* was a low percentage (3 percent) of the canopy cover prior to burning. The most important preburn variables for predicting postburn browse species abundance were preburn *C. canadensis* cover and the type of surficial deposit. Site conditions that are favorable to *C. canadensis* may be problematic for successful regeneration of browse species, especially if browse species are not present in the initial composition.

◆ **Cater, T.C. 1990.** Effect of vegetation competition on tree seedling establishment and growth in an upland, post-fire succession in Interior Alaska. Unpubl. M.S. Thesis. Univ. of Alaska Fairbanks. 48 pp.

Author abstract. Location and density of naturally occurring Picea glauca seedlings were measured five years following fire to document natural establishment patterns. To estimate effects of competition on these patterns, P. glauca and Betula papyrifera were sown as seeds and transplanted as seedlings into distinct patches of vegetation where either Equisetum arvense, Calamagrostis canadensis, or Populus tremuloides was dominant (> 90% cover). Naturally occurring P. glauca seedlings preferentially established where E. arvense was dominant. Similarly, P. glauca and B. papyrifera establishment and growth were greater in E. arvense patches and clipped plots. Thus, colonizing species inhibit establishment of latesuccessional species, with E. arvense being a weaker competitor than C. canadensis and P. tremuloides. Accumulated above and below-ground biomass were not good indicators of competitive ability. Environmental differences between patch types were positively correlated with the bioassay results: C. canadensis patches had thicker organic mats and cooler and wetter soils than other patch types.

◆ **Cater, T. C. and F. S. Chapin. 2000.** Differential effects of competition or microenvironment on boreal tree seedling establishment after fire. Ecology 81(4): 1086-1099.

Author abstract. We used a combination of surveys of natural vegetation and seed-sowing and seedling transplant experiments to determine the relative importance of competition and microenvironmental modification as mechanisms by which understory vegetation influences the establishment of tree seedlings in an Alaskan postfire boreal forest. Seedlings of white spruce (*Picea glauca*) and paper birch (*Betula papyrifera*) became established more frequently than expected in patches that were dominated by horsetail (*Equisetum arvense*), and less frequently than expected in patches of bluestem (*Calamagrostis canadensis*) and other vegetation. Similarly, birch and spruce, whether sown directly or transplanted as seedlings into horsetail-dominated patches generally showed greater survivorship, growth, and nitrogen accumulation (for birch only) than did those transplanted into bluestem or quaking aspen (*Populus tremuloides*) patches. Clipping experiments demonstrated that the presence of aboveground vegetation reduced survivorship (for birch only), growth (for both species), and nitrogen accumulation (for spruce only) in all patch types. Thus, the understory vegetation in all patch types competed with tree seedlings. However, patch × clipping interactions were either absent or could not explain the greater inhibition of seedling establishment by bluestem or aspen than by horsetail. The strong inhibitory effect of bluestem and aspen on the establishment of spruce and birch seedlings is best explained by the unfavorable temperature and moisture microenvironments in these patches, rather than by differential competition in patches of bluestem, horsetail, or aspen. Many asymmetrical species interactions that are thought to drive successional change may result more from the contrasting effects that species have on their environment than from resource competition among species.

◆ **Clautice, S.F. 1974.** Spruce and birch germination on different seedbeds and aspects after fire in interior Alaska . Unpubl. M.S. Thesis. Univ. of Alaska Fairbanks. 94 pp.

Author abstract. Picea glauca (Moench) Voss., Picea mariana (Mill.) B.S.P., and Betula papyrifera March seed were sown on three post fire seedbeds on north and south aspects the first spring following a forest fire. Germination of seeds, survival of seedlings, and natural revegetation were observed during the succeeding summer. Intense burning provided the best seedbeds for tree seed and southern aspects supported the best seedling growth. All three species sown germinated on both aspects. Germination occurred almost wholly on mineral soil but a minor amount occurred on ash. Charred organic matter was too dry to support germination. Mineral soil on the north slope was cold and constantly wet; while that on south slopes was warmer, it was intermittently dry, and less germination occurred on these drier slopes. Picea glauca and Picea mariana germination patterns were very similar. Flooding, browsing, and overgrowth by Marchantia polymorphia L. were main causes of Picea mortality on the north slope. and Betula papyrifera seedlings did not grow after germination on the north slope. Picea glauca grew largest on the south slope. Picea mariana seedlings were of similar size on both aspects. On the south slope Betula papyrifera seedlings developed two or more leaves, in contrast to the stunted development of those on the north aspect. Picea mariana showed the highest overall survival on both aspects, Picea glauca was intermediate, and Betula papyrifera had the lowest survival. The most common naturally occurring revegetation originated from seed on the south slope and from vegetative means on the north slope.

◆ **Foote, M. J. 1995.** The role of fire in the boreal forest of interior Alaska, Proceedings of the 1994 Society of American Foresters Annual Convention, 18-22 September 1994, Anchorage, AK. Society of American Foresters, Bethesda, MD. p. 179-184.

Author abstract: Fire burns 3,000-1,000,000 acres annually, It is a natural part of the ecology of the boreal forest of interior Alaska. Fire alters the site, growing conditions on the site, site resiliency, and the habitat of users of the site. It promotes site productivity by recycling nutrients, warming soils, melting permafrost, and exposing patches of mineral soil which make excellent surfaces for germinating seeds. It maintains landscape diversity and promotes young, highly productive forests and high quality food material. However, the unprotected mineral soil may erode and stability of some of the ice-rich permafrost sites is destroyed, at least for a time.

◆ **Johnstone, J.F. 2008.** A key for predicting postfire successional trajectories in black spruce stands of interior Alaska. U.S. Dept. of Agriculture, Forest Service, Pacific Northwest Research Station. GTR-PNW-767. 37 pp.

Author abstract: Black spruce (*Picea mariana* (Mill) B.S.P) is the dominant forest cover type in interior Alaska and is prone to frequent, stand-replacing wildfires. Through impacts on tree recruitment, the degree of fire consumption of soil organic layers can act as an important determinant of whether black spruce forests regenerate to a forest composition similar to the prefire forest, or to a new forest composition dominated by deciduous hardwoods. Here we present a simple, rule-based framework for predicting fire-initiated changes in forest cover within Alaska's black spruce forests. Four components are presented: (1) a key to classifying potential site moisture, (2) a summary of conditions that favor black spruce self-replacement, (3) a key to predicting postfire forest recovery in recently burned stands, and (4) an appendix of photos to be used as a visual reference tool. This report should be useful to managers in designing fire management actions and predicting the effects of recent and future fires on postfire forest cover in black spruce forests of interior Alaska.

◆ **Johnstone, J.F. 2003.** Fire and successional trajectories in boreal forest: implications for response to a changing climate. Global Change Biology (2010) 16, 1281–1295, doi: 10.1111/j.1365-2486.2009.02051.x 201 pp.

Author abstract. Predicting plant community responses to changing environmental conditions is a key element of forecasting and mitigating the effects of global change. Disturbance can play an important role in these dynamics, by initiating cycles of secondary succession and generating opportunities for communities of long-lived organisms to reorganize in alternative configurations. This study used landscape-scale variations in environmental conditions, stand structure, and disturbance from an extreme fire year in Alaska to examine how these factors affected successional trajectories in boreal forests dominated by black spruce. Because fire intervals in interior Alaska are typically too short to allow relay succession, the initial cohorts of seedlings that recruit after fire largely determine future canopy composition. Consequently, in a dynamically stable landscape, postfire tree seedling composition should resemble that of the prefire forest stands, with little net change in tree composition after fire. Seedling recruitment data from 90 burned stands indicated that postfire establishment of black spruce was strongly linked to environmental conditions and was highest at sites that were moist and had high densities of prefire spruce. Although deciduous broadleaf trees were absent from most prefire stands, deciduous trees recruited from seed at many sites and were most abundant at sites where the fires burned severely, consuming much of the surface organic layer. Comparison of pre- and postfire tree composition in the burned stands indicated that the expected trajectory of black spruce self-replacement was typical only at moist sites that burned with low fire severity. At severely burned sites, deciduous trees dominated the postfire tree seedling community, suggesting these sites will follow alternative, deciduous-dominated trajectories of succession. Increases in the severity of boreal fires with climate warming may catalyze shifts to an increasingly deciduous-dominated landscape, substantially altering landscape dynamics and ecosystem services in this part of the boreal forest.

◆ **Johnstone, J., L. Boby, E. Tissier, M. Mack, D. Verbyla, X. Walker**. **2009.** Postfire seed rain of black spruce, a semiserotinous conifer, in forests of interior Alaska. CJFR 39(8): 1575-1588, 10.1139/X09-068.

Author abstract. The availability of viable seed can act as an important constraint on plant regeneration following disturbance. This study presents data on seed quantity and quality for black spruce (Picea mariana (Mill.) B.S.P.), a semiserotinous conifer that dominates large areas of North American boreal forest. We sampled seed rain and viability for 2 years after fire (2005–2007) in 39 sites across interior Alaska that burned in 2004. All sites were dominated by black spruce before they burned. Structural equation modeling was used to assess the relative importance of prefire spruce abundance, topography effects, canopy fire severity, and distance to unburned stands in explaining variations in black spruce seed rain. Prefire basal area of spruce that remained standing after fire was a significant predictor of total seed rain, but seed viability was more strongly related to site elevation, canopy fire severity, and distances to unburned stands. Although positive relations between tree basal area and the size of the aerial seed bank may place a first constraint on seed availability, accurate prediction of postfire viable seed rain for serotinous conifers also requires consideration of the effects of abiotic stress and canopy fire severity on seed viability.

◆ **Johnstone, J.F., F.S. Chapin III, J. Foote, S. Kemmett, K. Price, and L. Viereck. 2004.** Decadal observations of tree regeneration following fire in boreal forests. Can. J. For. Res. 34:267-273.

Author abstract: This paper presents data on early postfire tree regeneration. The data were obtained from repeated observations of recently burned forest stands along the Yukon – British Columbia border and in interior Alaska. Postfire measurements of tree density were made periodically for 20–30 years, providing direct observations of early establishment patterns in boreal forest. Recruitment rates of the dominant tree species in both study areas were highest in the first 5 years after fire, and additional net establishment was not observed after 10 years. The postfire population of spruce (*Picea mariana* (Mill.) BSP and *Picea glauca* (Moench) Voss s.l.) remained constant after the first decade in the two study areas. Populations of aspen (*Populus tremuloides* Michx.) and lodgepole pine (*Pinus contorta* Dougl. ex Loud.var. *latifolia* Engelm.) both declined after 10 years in mixed-species stands along the Yukon – British Columbia border. Mortality rates of aspen and pine were positively correlated with their initial densities, indicating that thinning occurred as a density-dependent process. At all sites, measurements of stand density and composition made early were highly correlated with those made late in the monitoring period, indicating that patterns of stand structure initiated within a few years after fire are maintained through subsequent decades of stand development.

◆ **Johnstone, J.F., F.S Chapin, T.N. Hollingsworth, M.C. Mack, V. Romanovsky, M. Turetsky. 2010.** Fire, climate change, and forest resilience in interior Alaska. CJFR 40(7): 1302-1312, 10.1139/X10-061

Author abstract. In the boreal forests of interior Alaska, feedbacks that link forest soils, fire characteristics, and plant traits have supported stable cycles of forest succession for the past 6000 years. This high resilience of forest stands to fire disturbance is supported by two interrelated feedback cycles: (*i*) interactions among disturbance regime and plant–soil–microbial feedbacks that regulate soil organic layer thickness and the cycling of energy and materials, and (*ii*) interactions among soil conditions, plant regeneration traits, and plant effects on the environment that maintain stable cycles of forest community composition. Unusual fire events can disrupt these cycles and trigger a regime shift of forest stands from one stability domain to another (e.g., from conifer to deciduous forest dominance). This may lead to abrupt shifts in forest cover in response to changing climate and fire regime, particularly at sites with intermediate levels of moisture availability where stand-scale feedback cycles are only weakly constrained by environmental conditions. However, the loss of resilience in individual stands may foster resilience at the landscape scale, if changes in the landscape configuration of forest cover types feedback to stabilize regional patterns of fire behavior and climate conditions.

◆ **Johnstone, J.F. and E.S. Kasischke, 2005**. Stand-level effects of soil burn severity on postfire regeneration in a recently burned black spruce forest. Canadian Journal of Forest Research 35, 2151-2163.

Author abstract. This study tested whether variations in soil burn severity (soil organic layer consumption) influenced patterns of early postfire plant regeneration in a black spruce (*Picea mariana (Mill.) BSP*) forest in interior Alaska. Variations in burn severity were related to measurements of postfire tree seedling establishment and cover of plant growth forms observed 7–8 years after fire. Black spruce and trembling aspen (*Populus tremuloides Michx.*) showed significant and opposite responses of seedling density to changes in soil burn severity. Positive correlations between burn severity and aspen density and individual seedling biomass led to an increase of over three orders of magnitude in aspen standing biomass (aboveground, g/m2) from the least to most severely burned sites. Variations in aspen productivity and consequent effects on litter production and seedbed quality possibly explain the observed negative response of black spruce density to increasing burn severity. Variations in the cover of several plant growth forms were also strongly correlated with patterns of soil burn severity. Regenerating plant communities in low-severity sites had a greater cover of evergreen shrubs and graminoids, while high-severity sites had increased cover of aspen and acrocarpous mosses. Observations of regeneration patterns in the burn are largely consistent with experimental studies of severity effects and suggest that variations in soil burn severity can have a strong influence on landscape patterns of postfire forest recovery. In this case, increases in burn severity have shifted successional trajectories away from simple conifer self-replacement towards a trajectory of mixed conifer and deciduous dominance.

◆ **Johnstone, J.F., E.J.B. McIntire, E.J. Pedersen, G. King, and M.J.F. Pisaric. 2010.** A sensitive slope: estimating landscape patterns of forest resilience in a changing climate. Ecosphere 1:art14. http://dx.doi.org/10.1890/ES10-00102.1

Author abstract. Changes in Earth's environment are expected to stimulate changes in the composition and structure of ecosystems, but it is still unclear how the dynamics of these responses will play out over time. In long-lived forest systems, communities of established individuals may be resistant to respond to directional climate change, but may be highly sensitive to climate effects during the early life stages that follow disturbance. This study combined analyses of pre-fire and post-fire tree composition, environmental data, and tree ring analyses to examine landscape patterns of forest recovery after fire in the south-central Yukon, Canada, a climatically dry region of boreal forest where there is evidence of increasing drought stress. Pre-fire stand composition and age structures indicated that successional trajectories dominated by white spruce (*Picea glauca*) with little aspen (*Populus tremuloides*) comprised most of the study area during the last fire cycle. Although spruce seedling recruitment after the fire was highest at sites near unburned seed sources and where surface organic layers were shallow, spruce seedling densities were often insufficient to regenerate the pre-fire spruce forests. In particular, sites in the warmer topographic locations of the valley lowland and south-facing slopes typically had few spruce seedlings and instead were dominated by aspen. The opposite pattern was observed on north-facing slopes. Age reconstructions of pre-and post-fire stands indicate that future canopy composition is driven by initial post-fire recruitment and thus observed landscape differences in seedling recruitment are likely to be maintained through the next 100–200 years of succession. Observed results support the hypothesis that sites experiencing greater environmental stress show the lowest resilience to disturbance, or greatest compositional changes. Analyses of tree-ring responses to climate variables across the same landscape indicate that patterns of tree growth prior to a disturbance may be a useful predictor of landscape variations in forest resilience, allowing managers to better anticipate where future changes in forest composition are likely to occur.

◆ **Johnstone, J.F., Rupp, T.S., Olson, M., Verbyla, D., 2011**. Modeling impacts of fire severity on successional trajectories and future fire behavior in Alaskan boreal forests. Landsc. Ecol. 26, 487-500.

Author abstract. Much of the boreal forest in western North America and Alaska experiences frequent, stand-replacing wildfires. Secondary succession after fire initiates most forest stands and variations in fire characteristics can have strong effects on pathways of succession. Variations in surface fire severity that influence whether regenerating forests are dominated by coniferous or deciduous species can feedback to influence future fire behavior because of differences in forest flammability. We used a landscape model of fire and forest dynamics to explore the effects of different scenarios of surface fire severity on subsequent forest succession and potential fire activity in interior Alaska. Model simulations indicated that high levels of surface fire severity leading to a prolonged phase of deciduous forest dominance caused a reduction in landscape flammability and fewer large fire events. Under low surface fire severity, larger patches of contiguous conifer forest promoted fire spread and resulted in landscapes with shorter fire return intervals compared to scenarios of high surface severity. Nevertheless, these negative feedbacks between fire severity, deciduous forest cover, and landscape flammability were unable to fully compensate for greater fire activity under scenarios of severe climate warming. Model simulations suggest that the effects of climate warming on fire activity in Alaska's boreal forests may be partially but not completely mitigated by changes in fire severity that alter landscape patterns of forest composition and subsequent fire behavior.

◆ **Juday, G. P. and C. T. Dyrness, editors. 1985.** Early results of the Rosie Creek Fire Research Project., University of Alaska, Agricultural and Forestry Experiment Station, Fairbanks, Alaska, USA. Miscellaneous Publication 85-2

Author abstract. The purpose of this report is to provide a first account of the projects supported or about to be launched at the time of a December 4, 1984 meeting titled, 'Rosie Creek Fire Research Project, 1984 Research Progress Meeting.' None of the projects had been completed at the time of this meeting, which was only 17 months after the fire; all the results reported in this volume are preliminary. However, several of the research topics deal with immediate post-fire effects, so that a substantial base of information is available in those studies. In the case of projects that had not been launched at the time of the meeting, the authors were asked to report only their research rationale and approach. This volume is intended to provide information, which may be of immediate use, to practicing foresters and other resource management professionals in interior Alaska. It also serves as an accounting to the interested public as well as administrators and legislators who have supported the work. The meeting and information exchange reported here also serve to inform a diverse set of researchers of the full range of investigations underway, and alert them or others scientists to the opportunities for integration of research, other types of collaboration, and/or synthesis of results.

◆ **Lorente, L., W.F.J. Parsons, E.J.B. McIntire, and A.D. Munson. 2013.** Wildfire and forest harvest disturbances in the boreal forest leave different long-lasting spatial signatures. Plant Soil, 364, 1-2, pp. 39-54. Springer.

Author abstract. Natural disturbances leave long-term legacies that vary among landscapes and ecosystem types, and which become integral parts of successional processes at a given location. As humans change land use, not only are immediate post-disturbance patterns altered, but the processes of recovery themselves are likely altered by the disturbance. We assessed whether short-term effects on soils and vegetation that distinguish wildfire from forest harvest persist over 60 years after disturbance in boreal black spruce forests, or post-disturbance processes of recovery promote convergence of the two disturbance types. Using semi-variograms and Principal Coordinates of Neighbour Matrices, we formulated precise, a priori spatial hypotheses to discriminate spatial signatures following wildfire and forest harvest both over the short-(16-18 years) and long-term (62-98 years). Both over the short- and long-term, wildfire generated a wide spectrum of responses in soil and vegetation properties at different spatial scales while logging produced simpler patterns corresponding to the regular linear pattern of harvest trails and to pre-disturbance ericaceous shrub patches that persist between trails. Disturbance by harvest simplified spatial patterns associated with soil and vegetation properties compared to patterns associated with natural disturbance by fire. The observed differences in these patterns between disturbance types persist for over 60 years. Ecological management strategies inspired by natural disturbances should aim to increase the complexity of patterns associated with harvest interventions.

◆ **McRae, D.J., L.C. Duchesne, B. Freedman, T.J. Lynham, and S. Woodley. 2001.** Comparisons between wildfire and forest harvesting and their implications in forest management. Environmental Reviews*,* 2001, 9(4): 223-260, 10.1139/a01-010

Author abstract. Emulation silviculture is the use of silvicultural techniques that try to imitate natural disturbances such as wildfire. Emulation silviculture is becoming increasingly popular in Canada because it may help circumvent the political and environmental difficulties associated with intensive forest harvesting practices. In this review we summarize empirical evidence that illustrates disparities between forest harvesting and wildfire. As a rule, harvesting and wildfire affect biodiversity in different ways, which vary a great deal among ecosystem types, harvesting practices, and scale of disturbance. The scales of disturbance are different in that patch sizes created by logging are a small subset of the range of those of wildfire. In particular, typical forestry does not result in the large numbers of small disturbances and the small number of extremely large disturbances created by wildfires. Moreover, the frequency of timber harvesting is generally different from typical fire return intervals. The latter varies widely, with stand-replacing fires occurring in the range of 20 to 500 years in Canada. In contrast, harvest frequencies are dictated primarily by the rotational age at merchantable size, which typically ranges from 40 to 100 years. Forest harvesting does not maintain the natural stand-age distributions associated with wildfire in many regions, especially in the oldest age classes. The occurrence of fire on the landscape is largely a function of stand age and flammability, slope, aspect, valley orientation, and the location of a timely ignition event. These factors result in a complex mosaic of stand types and ages on the landscape. Timber harvesting does not generally emulate these ecological influences. The shape of cut blocks does not follow the general ellipse pattern of wind driven fires, nor do harvested stands have the ragged edges and unburned patches typically found in stand-replacing fires. Wildfire also leaves large numbers of snags and abundant coarse woody debris, while some types of harvesting typically leave few standing trees and not much large debris. Successional pathways following logging and fire often differ. Harvesting tends to favor angiosperm trees and results in less dominance by conifers. Also, understory species richness and cover do not always recover to the pre-harvest condition during the rotation periods used in typical logging, especially in eastern Canada and in old-growth forests. As well, animal species that depend on conifers or old-growth forests are affected negatively by forest harvesting in ways that may not occur after wildfire. The road networks developed for timber extraction cause erosion, reduce the areas available for reforestation, fragment the landscape for some species and ecological functions, and allow easier access by humans, whereas there is no such equivalency in a fire-disturbed forest. *Key words*: silviculture, forest management, clearcutting, forest conservation, wildfire, biodiversity.

◆ **Nilsson, M.C., 1998.** The charcoal effect in Boreal forests: mechanisms and ecological consequences. Oecologia 115, 419-426.

Author abstract. Wildfire is the principal disturbance regime in northern Boreal forests, where it has important rejuvenating effects on soil properties and encourages tree seedling regeneration and growth. One possible agent of this rejuvenation is fire-produced charcoal, which adsorbs secondary metabolites such as humus phenolics produced by ericaceous vegetation in the absence of fire, which retard nutrient cycling and tree seedling growth. We investigated short-term ecological effects of charcoal on the Boreal forest plant-soil system in a glasshouse experiment by planting seedlings of Betula pendula and Pinus sylvestris in each of three humus substrates with and without charcoal, and with and without phenol-rich Vaccinium myrtillus litter. These three substrates were from: (1) a high-productivity site with herbaceous ground vegetation; (2) a site of intermediate productivity dominated by ericaceous ground vegetation; and (3) an unproductive site dominated by Cladina spp. Growth of B. pendula was stimulated by charcoal addition and retarded by litter addition in the ericaceous substrate (but not in the other two), presumably because of the high levels of phenolics present in that substrate. Growth of P. sylvestris, which was less sensitive to substrate origin than was B. pendula, was unresponsive to charcoal. Charcoal addition enhanced seedling shoot to root ratios of both tree species, but again only for the ericaceous substrate. This response is indicative of greater N uptake and greater efficiency of nutrient uptake (and presumably less binding of nutrients by phenolics) in the presence of charcoal. These effects were especially pronounced for B. pendula, which took up 6.22 times more nitrogen when charcoal was added. Charcoal had no effect on the competitive balance between B. pendula and P. sylvestris, probably due to the low intensity of competition present. Juvenile mosses and ferns growing in the pots were extremely responsive to charcoal for all sites; fern prothalli were entirely absent in the ericaceous substrate unless charcoal was also present. Charcoal stimulated active soil microbial biomass in some instances, and also exerted significant although idiosyncratic effects on decomposition of the added litter. Our results provide clear evidence that immediately after wildfire fresh charcoal can have important effects in Boreal forest ecosystems dominated by ericaceous dwarf shrubs, and this is likely to provide a major contribution to the rejuvenating effects of wildfire on forest ecosystems.

◆ **Paragi, T.F. and Haggstrom, D. A. 2007**. Short-Term Responses of Aspen to Fire and Mechanical Treatments in Interior Alaska. Northern Journal of Applied Forestry, 24(2): 153-157.

Author abstract. Fire suppression and limited timber markets presently hinder maintenance of the early successional broad- leaved forest for wildlife habitat near settlements in interior Alaska. During 1999–2003, we evaluated the efficacy of prescribed burning, felling, and shearblading (with and without debris removal) to regenerate quaking aspen (Populus tremuloides). Treatments were conducted largely during the dormant period for aspen: prescribed burns in mid-May and mechanical treatments in late August through early April. Prescribed burns on loess hills produced 40,900–233,000 stems/ha by the second growing season. Low relative humidity, slope of more than 10°, southerly aspect, and juxtaposition to open areas produced fire behavior adequate to ensure top killing and vigorous sprouting response. Felling by chainsaw on loess hills produced 34,800–89,800 stems/ha, whereas dozer shearblading on glacial outwash (loam over gravel) produced 74,200–209,200 stems/ha (cleared portions and windrows combined) and a sandy loam floodplain produced 31,400–64,800 stems/ha. Pushing debris into windrows or scraping thick moss allowed warmer soils and produced greater sprouting on cleared sites relative to sections where debris or moss remained. Mechanical treatment were 25–75% of current prescribed fire costs, but debris accumulation may hinder access by browsing species and attract terrestrial predators of gallinaceous birds.

◆ **Peters**, V**.S., S.E. Macdonald, and M.R. T. Dale. 2005.** The interaction between masting and fire is key to white spruce regeneration. Ecology 86(7) 1744–1750

Author abstract. We used the mast-seeding tree *Picea glauca* (white spruce) to examine whether the timing of mast years relative to fire had a lasting effect on the density and timing of regeneration. We studied 17 fires that occurred in mast years and in years with low cone production between 1941 and 1994. Trees were carefully aged by crossdating procedures. Over the 59-yr period studied, there was significantly more regeneration after fires that occurred in mast years than after fires that occurred in years of low cone production. Spruce density was significantly lower after fires that occurred 1–3 years before a mast year than after fires during mast years. The cohort of trees that regenerated in the first mast year after a fire was critical to white spruce regeneration for fires that occurred 0–1 year before a mast year, but mast years occurring three or more years after a fire contributed few recruits. Our results suggest that masting is a key process that interacts with fire to shape stand composition in boreal mixedwoods. For species like white spruce, for which establishment is linked to disturbance, masting may have a contingent, historical effect on succession and landscape structure.

◆ **Potkin, M. 1997.** Fire history disturbance study of the Kenai Peninsula mountainous portion of the Chugach National Forest. Unpublished report. USDA Forest Service, Chugach National Forest, Anchorage, Alaska.

Author abstract. Forests in the vicinity of the Kenai Peninsula portion of the Chugach National Forest are of special ecological interest because of their transitional nature between coastal and interior forest types. The Continental Interior boreal forest and Maritime Pacific coast ecological regions merge on the Forest. Fire has historically been present in this century in the Kenai Mountains but whether fire is the important disturbance process creating structural and landscape diversity within this ecosystem is unknown. This report describes three distinct periods of fire frequency - prehistoric (pre 1740), settlement (1741-1913), and post-settlement (1914-1997). Fire reports on the Forest from 1914-1997 were summarized and attributed into a GIS data base documenting fire occurrences for the post-settlement period. A historic fire map was generated for known disturbance burn polygons. A historic land classification document containing maps and photographs, reveals widespread fire disturbances at the turn of the century, settlement period. The present study examined the fire history disturbances of three isolated mature forest areas to reconstruct the age distributions of living trees. Twenty-four historic burns were also examined, future work will reconstruct the age distributions of living trees sampled. Radiocarbon dates of soil charcoal were collected under mature forest stands to document pre-historic fire occurrences. Within the historic burns, remnants of older stumps and isolated residual trees reveal mature forests existed prior to disturbance. Needleleaf forests adjacent to these historic burns have ages greater than 200 ybp. The ages of living Lutz spruce and mountain hemlock within the mature forests sampled are greater than 200 ybp, subsurface soil charcoal is greater than 500 ybp. Although abiotic disturbances such as wind, snow avalanche, landslides, glacial recession, and flooding have been recognized for the important ways in which they influence the pattern of vegetation and tree recruitment on the Forest, the role of fire is now recognized as an important disturbance process over many millennia in this transitional climate. The historical records of fires and tree ages, together with the present mature forests and beetle kill fuel loads, suggest that the next interval of stand-regenerating fires is near. *[Compiler note: Table 1 includes notes on post-fire recruitment.]*

◆ **Rees, Daniel C., Juday, G.P. 2002.** Plant species diversity and forest structure on logged and burned sites in central Alaska. *Forest Ecology and Management* 155 (1-3): 291-302.

Author abstract. Natural fires and logging are two of the main disturbances affecting upland boreal forest in Alaska. The objectives of this study were to determine whether logged sites differ from burned sites in (1) overall plant species richness, 2) successional trajectories, and (3) species diversity at particular stand structural development stages. We compared plant species diversity on sites burned in natural fires to sites that were logged and not subsequently burned in central Alaska. We sampled 12 logged and 12 burned former upland white spruce (Picea glauca (Moench) Voss) forests in four stand development stages representing stand initiation (stage A), early stem exclusion (stage B), understory reinitiation (stage Q, and mature hardwood (stage D) stages. In this study the dates of disturbance varied from 1990 to 1994 in stage A, 1978 to 1983 in stage B, 1957 to 1965 in stage C, and 1900 to 1920 in stage D plots. All sites were similar in slope, aspect, and soil type. Vascular plants were identified to the species level (except for certain willows) and bryophytes and lichens were identified to the level of presumptive (usually unknown) species within family groups. Organic layer thickness was significantly greater on logged sites compared to burned sites overall and at each stage. Burned sites (all stages combined) supported more species (146) than logged sites (I 11), and more species at each stand development stage. Burned plots in stages A and B supported abundant cover of a few apparent fire specialist species (Ceratodon purpurcus (Hedw.) Brid., Marchantia polymorpha L. and Leptobryum pyriforme (Hedw.) Wils.) that were present in only minor amounts on logged sites. Burned plots exhibited higher species turnover from stage to stage and among all stages than logged plots. Species dominant in burned stage A plots were nearly absent in burned stage C and D plots, while logged stage A dominants, which were common mature forest species, increased in each subsequent stage. We compared floristic similarity between our disturbance plots and mature upland white spruce stands in Bonanza Creek Long-Term Ecological Research ALTER) site. Only five species found in the LTER dataset were not also present in this study, which suggests that nearly all species compositional change in our study area occurs during the first century after disturbance. Logged sites appear to begin and continue succession with a greater share of the original mature forest understory plants, while burned sites initiate succession with more distinctive and specialized plant species.

◆ **Schulze E.D., Wirth C., Mollicone D., Ziegler, W. 2005.** Succession after stand replacing disturbances by fire, wind throw, and insects in the dark Taiga of Central Siberia. *Oecologia*, 146, 77–88.

Author abstract. The dark taiga of Siberia is a boreal vegetation dominated by Picea obovata, Abies sibirica, and Pinus sibirica during the late succession. This paper investigates the population and age structure of 18 stands representing different stages after fire, wind throw, and insect damage. To our knowledge, this is the first time that the forest dynamics of the Siberian dark taiga is described quantitatively in terms of succession, and age after disturbance, stand density, and basal area. The basis for the curve-linear age/diameter relation of trees is being analyzed. (1) After a stand-replacing fire Betula dominates (4,000 trees) for about 70 years. Although tree density of Betula decreases rapidly, basal area (BA) reached >30 m2/ha after 40 years. (2) After fire, Abies, Picea, and Pinus establish at the same time as Betula, but grow slower, continue to gain height and eventually replace Betula. Abies has the highest seedling number (about 1,000 trees/ha) and the highest mortality. Picea establishes with 100-400 trees/ha, it has less mortality, but reached the highest age (>350 years, DBH 51 cm). Picea is the most important indicator for successional age after disturbance. Pinus sibirica is an accompanying species. The widely distributed "mixed boreal forest" is a stage about 120 years

after fire reaching a BA of >40 m2/ha. (3) Wind throw and insect damage occur in old conifer stands. Betula does not establish. Abies initially dominates (2,000-6,000 trees/ha), but Picea becomes dominant after 150-200 years since Abies is shorter lived. (4) Without disturbance the forest develops into a pure coniferous canopy (BA 40-50 m2/ha) with a self-regenerating density of 1,000 coniferous canopy trees/ha. There is no collapse of old-growth stands. The dark taiga may serve as an example in which a limited set to tree species may gain dominance under certain disturbance conditions without ever getting monotypic.

◆ **Wardle, D.A., O. Zackrisson, and M.-C. Nilsson. 1998.** The charcoal effect in Boreal forests: mechanisms and ecological consequences. Oecologia 115(3): 419-426.

Author abstract. Wildfire is the principal disturbance regime in northern Boreal forests, where it has important rejuvenating effects on soil properties and encourages tree seedling regeneration and growth. One possible agent of this rejuvenation is fire-produced charcoal, which adsorbs secondary metabolites such as humus phenolics produced by ericaceous vegetation in the absence of fire, which retard nutrient cycling and tree seedling growth. We investigated short-term ecological effects of charcoal on the Boreal forest plant-soil system in a glasshouse experiment by planting seedlings of *Betula pendula* and *Pinus sylvestris* in each of three humus substrates with and without charcoal, and with and without phenol-rich *Vaccinium myrtillus* litter. These three substrates were from: (1) a high-productivity site with herbaceous ground vegetation; (2) a site of intermediate productivity dominated by ericaceous ground vegetation; and (3) an unproductive site dominated by *Cladina* spp. Growth of *B. pendula* was stimulated by charcoal addition and retarded by litter addition in the ericaceous substrate (but not in the other two), presumably because of the high levels of phenolics present in that substrate. Growth of *P. sylvestris*, which was less sensitive to substrate origin than was *B. pendula*, was unresponsive to charcoal. Charcoal addition enhanced seedling shoot to root ratios of both tree species, but again only for the ericaceous substrate. This response is indicative of greater N uptake and greater efficiency of nutrient uptake (and presumable less binding of nutrients by phenolics) in the presence of charcoal. These effects were especially pronounced for *B. pendula*, which took up 6.22 times more nitrogen when charcoal was added. Charcoal had no effect on the competitive balance between *B. pendula* and *P. sylvestris*, probably due to the low intensity of competition present. Juvenile mosses and ferns growing in the pots were extremely responsive to charcoal for all sites; fern prothalli were entirely absent in the ericaceous substrate unless charcoal was also present. Charcoal stimulated active soil microbial biomass in some instances, and also exerted significant although idiosyncratic effects on decomposition of the added litter. Our results proved clear evidence that immediately after wildfire fresh charcoal can have important effects in Boreal forest ecosystems dominated by ericaceous dwarf shrubs, and this is likely to provide a major contribution to the rejuvenating effects of wildfire on forest ecosystems.

◆ Wimberly, M. C. and Z. Liu. 2013. Interactions of climate, fire, and management in future forest of the Pacific Northwest. Forest Ecology and Management. In press, DOI: 10.1016/j.foreco.2013.09.043.

Author abstract. A longer, hotter, and drier fire season is projected for the Pacific Northwest under future climate scenarios, and the area burned by wildfires is projected to increase as a result. Fuel treatments are an important management tool in the drier forests of this region where they have been shown to modify fire behavior and fire effects, yet we know relatively little about how treatments will interact with changing climate and expanding human populations to influence fire regimes and ecosystem services over larger area and longer time periods. As a step toward addressing this knowledge gap, this paper synthesizes the recent literature on climate, fire, and forest management in the Pacific Northwest to summarize projected changes and assess how forest management can aid in adapting to future fire regimes and reducing their negative impacts. Increased wildfire under future climates has the potential to affect many ecosystem services, including wildlife habitat, carbon sequestration, and water and air quality. Fuel treatments in dry forest types can reduce fire severity and size, and strategically-placed treatments can help to protect both property and natural resources from wildfire. Although increased rates of burning are projected to reduce carbon stocks across the region, research to date suggests that fuel treatments are unlikely to result in significant increases in carbon storage. Prescribed burning combined with thinning has been demonstrated to be effective at reducing fire severity across a variety of dry forest types, but there is uncertainty about whether changing climate and increasing human encroachment into the wildland–urban interface will limit the use of prescribed fire in the future. Most fire research has focused on the dry forest types, and much less is known about the ecological impacts of increased wildfire activity in the moist forests and the potential for adapting to these changes through forest management. To address these knowledge gaps, future research efforts should build on the Pacific Northwest's legacy of integrated regional assessments to incorporate broad-scale climatic drivers with processes operating at the stand and landscape levels, including vegetation succession, fire spread, treatment effects, and the expansion of human populations into wildland areas. An important outcome of this type of research would be the identification of localized "hot spots" that are most sensitive to future changes, and are where limited resources for fire management should be concentrated.

◆ **Zasada, J. and R. Norum. 1986.** Prescribed Burning White Spruce Slash in Interior Alaska. Northern Journal of Applied Forestry 3(1): 16-18.

Author abstract. Broadcast burning following harvesting on flood-plain sites in Alaska substantially decreased residual organic material and increased exposed mineral soil. Two forest types were studied: white spruce/alder/feathermoss and white spruce/alder/lingonberry/feathermoss. The latter site contained permafrost. Fuel was reduced 67% and 81%, respectively; organic horizon thickness was decreased 43% to 2.9 in (7.4 cm) and 55% to 2.5 in (6.4 cm), respectively; and mineral soil exposure was 13% and 8%, respectively. Burning created good conditions for planting on both types. In addition, mechanical site preparation to increase mineral soil exposure appears to be necessary to achieve adequate, well-distributed regeneration from seed.

◆ **Zasada, J.C., R.A. Norum, R.M. Van Veldhuizen, C.E. Teutsch. 1983.** [Artificial regeneration of trees and tall shrubs in experimentally burned upland black spruce/feather moss stands in Alaska.]() CJFR 13(5): 903-913, 10.1139/x83-120

Author abstract. Fall seed-dispersing species, birch (*Betula papyrifera* Marsh.), alder (*Alnus crispa* (Ait.) Pursh), and black spruce *Picea mariana* (Mill.) B.S.P.), and summer-seeding species, aspen (*Populus tremuloides* Michx.), balsam poplar (*P. balsamifera* L.), feltleaf willow (*Salix alaxensis* (Anderss.) Cov.), Scouler willow (*Salix scouleriana* Barratt), and Bebb willow (*Salix bebbiana* Sarg.), were artificially sown on seedbeds created by experimental burning in the upland black spruce/feather moss forest types in interior Alaska. At least 40% of the seeds dispersed in the fall had germinated before dispersal of summer seeds began. Germination occurred on moderately and severely burned seedbeds but not on scorched and lightly burned surfaces. Seedling survival occurred almost exclusively on severely burned surfaces. After 3 years, 82% of the plots containing some severely burned surfaces and sown with seeds from species seeded in the fall were stocked whereas 32% of the plots sown with species seeded in the spring and with the same seedbed condition were stocked.

WILDLIFE

◆ **Andrews, J.H. 1998.** The impact of moose browsing on Populus in the Susitna Valley, southcentral Alaska . Unpubl. M.S. Thesis. Univ. of Alaska Fairbanks. 125 pp.

Author abstract. Twenty balsam poplar *(Populus balsamifera* L.) and twenty quaking aspen *(Populus tremuloides* Michx.) sites were sampled to determine the impact moose browsing has upon early tree growth and forest stand structure. Dominant heavily browsed stems from each of the 20 plots per site were sampled for top height, stump diameter, age, and stem quality and compared with available dominant, unbrowsed stems. Remaining stems in the plots were tallied according to species, 0.5 m height class, browse intensity, and mortality. Unbrowsed tree heights were 2.1-3.5 times taller and diameters were 1.4-2.6 times greater than heavily browsed stems within the same age class. Preferred browse species stems taller than 0.5 m had browse damage greater than 91.0 percent. The occurrence of stain and decay were twice as great in heavily browsed stems as in unbrowsed stems. The intensity of browsing and reduced growth can extend the rotation age or favor dominance of non-browse species.

◆ **Angell, A. C. and K. Kielland. 2009.** Establishment and growth of white spruce on a boreal forest floodplain: interactions between microclimate and mammalian herbivory. Forest Ecology and Management 258:2475-2480.

Author abstract. White spruce (*Picea glauca* (Moench) Voss) is a dominant species in late-successional ecosystems along the Tanana River, interior Alaska, and the most important commercial timber species in these boreal floodplain forests. Whereas white spruce commonly seed in on young terraces in early primary succession, the species does not become a conspicuous component of the vegetation until after 60–80 years. To address what abiotic and/or biotic factors may explain the paucity of spruce in earlier stages of succession, we examined germination and growth of planted white spruce seedlings across an environmental gradient that included variation in soil physico-chemical properties in the presence and absence of mammal browsing. The effect of browsing pressure over the first four years after planting was most noticeable on the older terraces. Likewise, direct effects of hare browsing on spruce seedling mortality were only manifested at the oldest sites. Spruce germination and survival was inversely proportional to soil cation concentrations, which was largely controlled by temperature-driven evapotranspiration. High light intensities and high air temperatures significantly reduced seedling growth, whereas variation in soil moisture only explained a significant amount of variation in seedling survival. Temperatures within the needle clusters on terminal shoots reached values that adversely affect photosynthesis (>32 °C) on multiple occasions over the growing season. We conclude that the direct (temperature) and indirect (soil chemistry) effects of high insolation are major factors constraining spruce performance on early successional terraces, and that these effects can be significantly exacerbated by mammal browsing on associated deciduous vegetation.

◆ **Angell, A.C. 2007.** Effects of moose browsing on the establishment and growth of white spruce seedlings (Picea glauca (Moench) Voss) on the Tanana River . Unpubl. M.S. Thesis. 83 pp.

White spruce (Picea glauca (Moench) Voss) is an important tree species in late-successional forests on the Tanana River floodplain. Although spruce seed in young terraces, trees do not become a conspicuous component of the vegetation until after 60-80 years. To address what abiotic and biotic factors may explain the paucity of spruce in early succession, I examined germination and growth of spruce seedlings across an environmental gradient of soil physico-chemical properties and cover of deciduous vegetation. To test the hypothesis that moose browsing on willows has a negative effect on spruce seedling performance, due to browsing-induced changes in edaphic and microclimatological conditions, I measured several ecophysiological responses of seedlings to variation in soil chemistry and radiation in the presence and absence of browsing. Despite high browsing pressure, herbivory had moderate effects on most environmental variables. Spruce germination and survival were inversely proportional to soil cation concentrations. High light and air temperatures significantly reduced seedling growth, while soil moisture influenced survival. Temperatures within the needle clusters on lateral shoots reached values that could denature photosynthetic enzymes. I conclude that the direct (temperature) and indirect (soil chemistry) effects of radiation are major factors that constrain spruce performance on early successional terraces.

◆ **Collins, William B., and Schwartz, Charles C. 1998.** Logging in Alaska's boreal forest: creation of grasslands or enhancement of moose habitat. Alces, 34 (2): 355-374.

Author abstract. Data collected from 96 sites during 1990-95 showed that timber harvest in boreal forests of Alaska can greatly enhance or severely reduce moose (Alces alces) habitat quality, depending on forest management objectives, timing and methods of harvest, and post-logging site preparation. Overstorey removal associated with timely exposure of mineral soil favours establishment of early successional hardwoods important as moose browse. A combination of clear-cutting and soil scarification on mesic sites mimics fire, windfall, and fluvial erosion, important natural forces that drive regeneration of the boreal forest. When cut during dormancy, aspen (Populus tremuloides) and balsam poplar (P. balsamifera) regenerate prolifically by root and stump sprouting. However, harvest of paper birch (Betula papyrifera) or white spruce (Picea glauca) with little or no disturbance to the organic mat covering the forest floor often results in establishment of a long-lived herbaceous disclimax dominated by bluejoint reedgrass (Calamagrostis canadensis). This disclimax may persist for 25 to 100 years or more, limiting re-establishment of important deciduous browse species utilized by moose. With proper timber harvest, soil scarification, and good seedling establishment, carrying capacity for moose based upon forage supply can increase 20-45 fold (4-9 moose/km^2) over mature forest. Increases of this magnitude are also observed following wild fire. Estimates of carrying capacity following poor harvest practices with no scarification seldom exceed 0.2 moose/km, similar to that of mature forest. Properly regenerated clearcuts yield high quantities of moose browse for approximately 20 years following logging. The importance of appropriate timber harvesting practices for moose in the boreal forest ecosystem in Alaska is discussed.

◆ **MacCracken, J.G. and L.A. Viereck. 1990.** Browse regrowth and use by moose after fire in interior Alaska. Northwest Science 64:11-18.

Author abstract. A fire which began in late May 1983 burned >3000 ha of forests of quaking aspen (Populus tremuloides), paper birch (Betula papyrifera) and white and black spruce (Picea glauca, P. mariana) in Rosie Creek, near Fairbanks, Alaska. Within 2 months, regrowth of browse was abundant from sprouting of roots and stumps of quaking aspen, paper birch and willows (Salix spp.). Generally, aspen sites produced the most browse, followed by white spruce, birch and black spruce. Composition of the pre-fire plant community, which was directly related to stand age, strongly influenced browse regrowth. Seedling establishment of browse species was evident after 3 yr. Moose (Alces alces) foraged on the burned area during the first winter after the fire. Browse ranged from 1 to 46%, was greatest on willows, and was significantly correlated with both stem counts and biomass. Crude protein and mineral concentrations differed among browse species and decreased as time after the fire increased. This suggests that fire can have immediate benefits to moose by production of substantial browse within a few months.

◆ **Pusenius, J. and R.S. Ostfeld. 2002.** Mammalian predator scent, vegetation cover and tree seedling predation by meadow voles . Ecography, v. 25, no. 4 (Aug. 2002) pp. 481-487.

Author abstract. Herbivores are thought to respond to the increased risk of attack by predators during foraging activities by concentrating feeding in safe habitats and by reducing feeding in the presence of predators. We tested these hypotheses by comparing tree seedling predation by meadow voles within large outdoor enclosures treated either with scent of large mammalian predators (red fox, bobcat, coyote) or a control scent (vinegar). In addition, we compared the distribution of voles in relation to naturally occurring variation in vegetation cover and the tendency of voles to attack tree seedlings planted in small patches with cover manipulation (intact, reduced or removed cover). Predator scent did not affect the rate or spatial distribution of tree seedling predation by voles, nor did it affect giving up densities (a surrogate of patch quitting harvest rate), survival rates, body size or habitat distribution of voles. In both predator scent and vinegar treatments voles preferred abundant vegetation providing good cover, which was also the site of almost all tree seedling predation. We conclude that large mammalian predator scent does not influence the perception by voles of the general safety of habitat, which is more strongly affected by the presence of cover.

◆ **Putman, W.E. and J.C. Zasada. 1985.** Raven damage to plastic seeding shelters in Interior Alaska. North. J. Applied For. 2(1985):41-42

Author abstract. Two types of plastic seeding shelters are being tested in interior Alaska for regenerating white spruce. Raven damage to shelters has been observed on sites seeded shortly after burning. Damage averaged 6 8% with cones and 50% with funnels on a burned upland site, and 26% with funnels on a burned floodplain site. Damage was highly variable and appeared to be related to time of sowing and vegetation development near the seedspots. Care should be taken when considering use of seeding shelters after burning.

◆ **Richmond, A.P. 1985.** Moose-browsing damage in a recently thinned stand of sapling paper birch in interior Alaska. Agroborealis 1985, V. 17 (JAN. 1985) P. 7.

Author abstract. The University of Alaska's School of Agriculture and Land Resources Management has, since 1980, been conducting intensive research in the field of forest management with the goal of identifying economically and biologically feasible forestry practices for use in managing interior forests. One of the practices being examined is thinning, i.e., a portion of a stand is removed to promote growth on the remaining trees. Although thinnings normally decrease the total volume of timber which can be harvested from a stand, the value of the stand increases due to the large size of the trees at harvest. Thinnings can be done on both a commercial and precommercial basis depending on the tree species , the management objectives for the stand, and the anticipated value of the stand at harvest.
The trees removed in a commercial thinning can be sold as fuelwood, poles, pilings or sawlogs, thereby helping to pay the cost of thinning. Precommercial thinnings are performed in sapling stands where the material to be removed does not have any commercial value. In this case, the increase in value of the thinned stand has to be great enough to offset or justify the treatment cost. The response of the stands to the thinning treatments is being assessed with regard to diameter-height growth and post-treatment damage. Types of damage most common to thinned stands are windthrow, snow breakage, and insect attack. A recent precommercial thinning in a sapling paper birch stand suffered some browsing damage from moose which may have a bearing on future intensive management of this tree species. The potential for moose browse damage of the residual trees had been recognized prior to the thinning treatment.
The stand was known to receive heavy use in winter by moose, as evidenced by the large number of broken and browsed trees observed over the two previous winters. As many as four moose had been observed i11 the area at one time. During the thinning-treatment period, a moose which had apparently broken the tops of four residual birch trees was observed in a portion of the stand already thinned. Studies of moose feeding habits have found that paper birch is a major food source and comprises between 12 and 35 per cent of total diet (Peterson 1955). This is supported by other research that indicates birch is heavily used when available (McMillan 1953, Dodds 1960. Bergerud and Manuel 1968, Crete and Bedard 1975. Telfer and Cairns 1978). Palatability (preference) for birch has been rated as equal to willows (Hosely 1949).

INSECTS AND DISEASES

◆ **Allen, J.L., Wesser, S., Markon, C.J., Winterberger, K.C., 2006.** Stand and landscape level effects of a major outbreak of spruce beetles on forest vegetation in the Copper River Basin, Alaska. For. Ecol. Manage. 227, 257-266.

Author abstract. From 1989 to 2003, a widespread outbreak of spruce beetles (Dendroctonus rufipennis) in the Copper River Basin, Alaska, infested over 275,000 ha of forests in the region. During 1997 and 1998, we measured forest vegetation structure and composition on one hundred and thirty-six 20-m x 20-m plots to assess both the immediate stand and landscape level effects of the spruce beetle infestation. A photo-interpreted vegetation and infestation map was produced using color-infrared aerial photography at a scale of 1:40,000. We used linear regression to quantify the effects of the outbreak on forest structure and composition. White spruce (Picea glauca) canopy cover and basal area of medium-to-large trees [>= 15 cm diameter-at-breast height (1.3 m, dbh)] were reduced linearly as the number of trees attacked by spruce beetles increased. Black spruce (Picea mariana) and small diameter white spruce (< 15 cm dbh) were infrequently attacked and killed by spruce beetles. This selective attack of mature white spruce reduced structural complexity of stands to earlier stages of succession and caused mixed tree species stands to lose their white spruce and become more homogeneous in overstory composition. Using the resulting regressions, we developed a transition matrix to describe changes in vegetation types under varying levels of spruce beetle infestations, and applied the model to the vegetation map. Prior to the outbreak, our study area was composed primarily of stands of mixed white and black spruce (29% of area) and pure white spruce (25%). However, the selective attack on white spruce caused many of these stands to transition to black spruce dominated stands (73% increase in area) or shrublands (26% increase in area). The post-infestation landscape was thereby composed of more even distributions of shrubland and white, black, and mixed spruce communities (17-22% of study area). Changes in the cover and composition of understory vegetation were less evident in this study. However, stands with the highest mortality due to spruce beetles had the lowest densities of white spruce seedlings suggesting a longer forest regeneration time without an increase in seedling germination, growth, or survival.

◆ **Berg, E., J. D. Henry, C. Fastie, A. De Volder, and S. Matsuoka. 2006**. Spruce beetle outbreaks on the Kenai Peninsula, Alaska, and Kluane National Park and Reserve, Yukon Territory: Relationship to summer temperatures and regional differences in disturbance regimes. Forest Ecology and Management 227(3):219-232

Author Abstract. When spruce beetles (Dendroctonus rufipennis) thin a forest canopy, surviving trees grow more rapidly for decades until the canopy closes and growth is suppressed through competition. We used measurements of tree rings to detect such growth releases and reconstruct the history of spruce beetle outbreaks at 23 mature spruce (Picea spp.) forests on and near the Kenai Peninsula, Alaska and four mature white spruce (Picea glauca) forests in Kluane National Park and Reserve, Yukon Territory. On the Kenai Peninsula, all stands showed

evidence of 1–5 thinning events with thinning occurring across several stands during the 1810s, 1850s, 1870–1880s, 1910s, and 1970–1980s, which we interpreted as regional spruce beetle outbreaks. However, in the Kluane region we only found evidence of substantial thinning in one stand from 1934 to 1942 and thinning was only detected across stands during this same time period. Over the last 250 years, spruce beetle outbreaks therefore occurred commonly among spruce forests on the Kenai Peninsula, at a mean return interval of 52 years, and rarely among spruce forests in the Kluane region where cold winter temperatures and fire appear to more strongly regulate spruce beetle population size. The massive 1990s outbreaks witnessed in both regions appeared to be related to extremely high summer temperatures. Recent outbreaks on the Kenai Peninsula (1971–1996) were positively associated with the 5-year backwards running average of summer temperature. We suggest that warm temperature influences spruce beetle population size through a combination of increased overwinter survival, a doubling of the maturation rate from 2 years to 1 year, and regional drought-induced stress of mature host trees. However, this relationship decoupled after 1996, presumably because spruce beetles had killed most of the susceptible mature spruce in the region. Thus sufficient numbers of mature spruce are needed in order for warm summer temperatures to trigger outbreaks on a regional scale. Following the sequential and large outbreaks of the 1850s, 1870–1880s, and 1910s, spruce beetle outbreaks did not occur widely again until the 1970s. This suggests that it may take decades before spruce forests on the Kenai Peninsula mature following the 1990s outbreak and again become susceptible to another large spruce beetle outbreak. However, if the recent warming trend continues, endemic levels of spruce beetles will likely be high enough to perennially thin the forests as soon as the trees reach susceptible size.

◆ **Boggs K. , M. Sturdy, D.J. Rinella, M.J. Rinella. 2008.** White spruce regeneration following a major spruce beetle outbreak in forests on the Kenai Peninsula, Alaska. Forest Ecology and Management 255 (2008) 3571–3579

Author Abstract. Between 1987 and 2000, a spruce beetle (Dendroctonus rufipennis) outbreak infested 1.19 million ha of spruce (Picea spp.) forests in Alaska, killing most of the large diameter trees. We evaluated whether these forests would recover to their pre-outbreak density, and determined the site conditions on which spruce germinated and survived following the spruce beetle outbreak in forests of the Anchor River watershed, Kenai Peninsula, Alaska. White spruce (Picea glauca) and Lutz's spruce (Picea lutzii), a hybrid between white and Sitka spruce (Picea sitchensis), dominate the study area. We measured the pre- and post-outbreak density of spruce in 108 3 m _ 80 m plots across the study area by recording all live trees and all dead trees >1.5 m tall in each plot. To determine the fine scale site conditions on which spruce germinated and survived, we measured ground surface and substrate characteristics within 20 cm circular plots around a subset of post-outbreak spruce seedlings. The density of post-outbreak spruce (855/ha) was adequate to restock the stands to their pre-outbreak densities (643/ha) for trees >1.5 m tall. We could not accurately estimate recovery for pre-outbreak spruce seedlings because dead seedlings may have decayed in the 5–18 years since the beetle outbreak occurred. At the fine scale, spruce that germinated post-outbreak grew on a wide variety of substrates including downed log, stump, mesic organic mat, peat, hummocks and mineral soil. They exhibited a strong preference for downed logs (53%) and stumps (4%), and most (91%) of the downed logs and stumps that spruce rooted on were heavily decayed. This preference for heavily decayed logs and stumps was especially evident given that their combined mean cover was only 2% in the 3 m _ 80 m plots. Within the 3 m _ 80 m plots, spruce seedling survival was negatively correlated with bluejoint (Calamagrostis canadensis) litter cover.

◆ **Boucher, T.V., Mead, B.R., 2006.** Vegetation change and forest regeneration on the Kenai Peninsula, Alaska following a spruce beetle outbreak, 1987–2000. For. Ecol. Manage. 227, 233-246.

Author abstract. Forests of the Kenai Peninsula, Alaska experienced widespread spruce (Picea spp.) mortality during a massive spruce beetle (Dendroctonus rufipennis) infestation over a 15-year period. In 1987, and again in 2000, the U.S. Forest Service, Pacific Northwest Research Station, Forest Inventory and Analysis Program conducted initial and remeasurement inventories of forest vegetation to assess the broad-scale impacts of this infestation. Analysis of vegetation composition was conducted with indirect gradient analysis using nonmetric multidimensional scaling to determine the overall pattern of vegetation change resulting from the infestation and to evaluate the effect of vegetation change on forest regeneration. For the latter we specifically assessed the impact of the grass bluejoint (Calamagrostis canadensis) on white spruce (Picea glauca) and paper birch (Betula papyrifera) regeneration. Changes in vegetation composition varied both in magnitude and direction among geographic regions of the Kenai Peninsula. Forests of the southern Kenai Lowland showed the most marked change in composition indicated by relatively large distances between 1987 and 2000 measurements in ordination space. Specific changes included high white spruce mortality (87% reduction in basal area of white spruce > 12.7 cm diameter-at-breast height (dbh)) and increased cover of early successional species such as bluejoint and fireweed (Chamerion angustifolium). Forests of the Kenai Mountains showed a different directional change in composition characterized by moderate white spruce mortality (46% reduction) and increased cover of late-successional mountain hemlock (Tsuga mertensiana). Forests of the Gulf Coast and northern Kenai Lowland had lower levels of spruce mortality (22% reduction of Sitka spruce (Picea sitchensis) and 28% reduction of white spruce, respectively) and did not show consistent directional changes in vegetation composition. Bluejoint increased by >= 10% in cover on 12 of 33 vegetation plots on the southern Kenai Lowland but did not increase by these amounts on the 82 plots sampled elsewhere on the Kenai Peninsula. Across the Kenai Lowland, however, regeneration of white spruce and paper birch did not change in response to the outbreak or related increases in bluejoint cover from 1987 to 2000. Although some infested areas will be slow to reforest owing to few trees and no seedlings, we found no evidence of widespread reductions in regeneration following the massive spruce beetle infestation.

◆ **Fastie, C.F. 1996**. Tree ring evidence for historical outbreaks of spruce bark beetles on the Kenai Peninsula, Alaska**.** Alaska branching out 15(3): 2.

Need to check with Celia for copy

◆ **Holsten, E.H., R.A. Werner, and R.L. DeVelice. 1995.** Effects of a spruce beetle (Coleoptera:Scolytidae) outbreak and fire on Lutz spruce in Alaska. Environmental Entomology 24(6):1539-1547.

Author abstract. The spruce beetle, Dendroctonus rufipennis (Kirby), has had a major effect on the spruce forests of southcentral Alaska. In one area of the Chugach National Forest, 51% of the Lutz spruce, Picea glauca x lutzii Little, or nearly 90% of the commercial stand volume was killed by spruce beetles during a 16-yr period. The majority of the tree losses occurred during the first 10 yr of the outbreak. Tree species composition remained essentially the same after the outbreak. Forest structure changed with decreased tree density, and species richness declined significantly on the unburned, spruce beetle-effected plots. This reduction in plant diversity was probably a result of the significant increase, and competitive advantage, of bluejoint grass, Calamagrostis canadensis (Michaux) Beauvois, and fireweed, Epilobium angustifolium L., in the heavily beetle-effected plots. Although species richness did not change 7 yr after a prescribed fire, species composition did change. Specifically, the occurrence and percentage of bluejoint and fireweed cover significantly increased.

◆ **Lewis, K.J., and E. M. Hansen. 1991.** Survival of *Inonotus tomentosus* in stumps and subsequent infection of young stands in north central British Columbia. Canadian Journal of Forest Research 21(7): 1049-1057

Author abstract: Distribution of tomentosus root disease in spruce (*Piceaglauca* (Moench) Voss and *P*. *glauca* × *engelmannii* Engelm.) and pine (*Pinusconforta* var. *latifolia* Engelm.) stumps in 1- to 30-year-old harvest units, survival of *Inonotus tomentosus* (FR) Teng in stumps, and infection of regeneration trees were examined by transect surveys and root excavations. The number of diseased stumps ranged from 8 to 71 per hectare (2.1–27.5%); these were in patches, commonly two to three stumps each. Viable mycelium was found in 80 and 53% of the 30-year-old spruce and pine stumps, respectively. Distal growth by *I*. *tomentosus* in roots ceased shortly after harvest. Narrow decay and stain columns were observed in 1- and 2-year-old spruce stumps. In older stumps, the fungus had colonized the sapwood and bark. In pine, colonization of the bark and cambium was common at all stump ages. Spruce stumps, with longer, horizontally oriented roots and a greater percentage of colonized roots, caused more infections of regeneration than pine stumps (14 and 5%, respectively, of the five regeneration trees closest to each stump). Regeneration trees had a 25% chance of infection if planted within 2 m of decayed spruce stumps and 0.5 m of decayed pine stumps. The probability of infection decreased to 10% at 3.75 and 2.75 m from spruce and pine stumps, respectively. Both spruce and pine regeneration were infected, often at points of disruption in the bark, such as a feeder root or root branch.

◆ **Packee, E.C. 1997.** Restoring spruce beetle-impacted forests in Alaska. Agroborealis 1997 29(1): 18-24.

Compiler abstract. This article reviews the ecology and impacts of spruce bark beetle *(Dendroctonus rufipennis)* in Alaskan forests, and recommends actions for restoring forests to maintain spruce and mixed stands of various ages, densities, and structures. The author emphasizes collection of local spruce seed, discourages use of non-native species, and discusses restoration actions for riparian zones.

◆ **Werner, R.A. 2002.** Effect of ecosystem disturbance on diversity of bark and wood-boring beetles (Coleoptera: Scolytidae, Buprestidae, Cerambycidae) in white spruce (Picea glauca (Moench) Voss) ecosystems of Alaska [microform] . Res. Pap. PNW-RP-546. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 15 pp.

Author abstract. Fire and timber harvest are the two major disturbances that alter forest ecosystems in interior Alaska. Both types of disturbance provide habitats that attract wood borers and bark beetles the first year after the disturbance, but populations then decrease to levels below those in undisturbed sites. Populations of scolytids, buprestids, and cerambycids are compared 1, 5, and 10 years after burning and timber harvest on flood-plain and upland white spruce sites. This paper reports the effects of ecosystem disturbance, such as silvicultural practices and prescribed fire, on the diversity of wood-inhabiting bark beetles and wood borers in upland and flood-plain white spruce stands in interior Alaska.

◆ **Werner, R.A., E.H. Holsten, S.M. Matsuoka, and R.E. Burnside. 2006.** Spruce beetles and forest ecosystems in south-central Alaska: a review of 30 years of research. Forest Ecology and Management 227(3):195-206.

Author abstract. From 1920 to 1989, approximately 847,000 ha of Alaska spruce (*Picea* spp.) forests were infested by spruce beetles (*Dendroctonus rufipennis*). From 1990 to 2000, an extensive outbreak of spruce beetles caused mortality of spruce across 1.19 million ha of forests in Alaska; approximately 40% more forest area than was infested the previous 70 years. This review presents some of the most important findings from a diversity of research and management projects from 1970 to 2004 to understand the biology, ecology, and control of this important forest insect, and the causes and effects of their outbreaks. It is suggested that future research should examine the long-term effects of the spruce beetle outbreaks and climate variability on forest ecosystems in the region. Research into how different management actions facilitate or interrupt natural successional processes would be particularly useful.

NON-NATIVE AND INVASIVE SPECIES

◆ **Alaska Department of Natural Resources Division of Forestry. 2004**. Frequently asked questions about reforestation with non-native trees in southcentral Alaska. Unpublished fact sheet. 3 pp.

Compiler abstract: This fact sheet addresses frequently asked questions about survival, susceptibility to disease, wildfire risk, wood value, and wildlife habitat impacts of lodgepole pine and Siberian larch planting in Alaska.

◆ **Alden, J. 2006.** Field survey of growth and colonization of non-native trees on mainland Alaska. US Forest Service, Pacific Northwest Res. Sta. PNW-GTR-664.

Need abstract –***Jeff G. sending in mail***

◆ **Alden, J.N. 1988.** Implications of research on lodgepole pine introduction in interior Alaska . U.S. Dept. of Agriculture, Forest Service, Pacific Northwest Research Station Res. Pap. PNW-RP 402. Portland, OR. 24 pp.

Author abstract. Growth, winter injury, and mortality were evaluated for 12-year-old trees of 11 subarctic lodgepole pine provenances and a jack pine provenance at Fairbanks, Alaska. Provenances from northeast British Columbia grew more than 0.003 cubic meter of wood per tree annually from 9 to 12 years after outplanting. The species sustained snow damage and winter injury, however, and could be at high risk in long-term management on severe sites in Alaska. Provenance x site interactions were not significant for mortality, tree height, and volume after the same stock grew for 10 seasons at Fairbanks and Whitehorse, Yukon. Height and environmental injury of 3-year-old seedlings from 18 subarctic lodgepole pine and a jack pine x lodgepole pine swarm from Fort Nelson River, British Columbia, were evaluated at two sites in the interior and one site in south-central Alaska. Seedlings from high-altitude provenances grew more slowly and sustained less environmental injury after outplanting than seedlings from low-altitude provenances. More seedlings of the jack pine x lodgepole pine provenance sustained injury, but they grew taller than seedlings of the lodgepole pine provenances in the nursery and after two growing seasons in the field. Additional research is necessary to identify and determine growth and yield of superior jack, lodgepole, and jack pine x lodgepole pine provenances for a wide range of sites in Alaska.

◆ **Crossley, D. I. 1956.** Mechanical scarification and strip clear-cutting to induce lodgepole pine regeneration . Canada Dept. of Northern Affairs and Natural Resources. Forestry Branch, Forest Research Division. Tech. Note. No. 34. 14 pp.

Author abstract. Lodgepole pine *(Pinus contorta Dougl. var. latifolia Engelm.)* is recognized as a fire type that regenerates readily after the humus has been destroyed by fire and seed released from the serotinous cones opened by heat. However, a very wide variation in stocking is the usual result. From a study of the causes of variation in stocking on a large regenerated 16-year-old burn on the Kananaskis Forest Experiment Station in Alberta, Horton (1953) found that 25 per cent of the area was heavily overstocked and stagnating, and an additional 23 per cent was lightly overstocked and would probably stagnate in the future. He concluded that the usual tendency after fire was toward overstocking on the better sites. Stagnation in lodgepole pine stands is a difficult condition for the silviculturist to overcome and the best defence against it appears to be the prevention of over-abundant regeneration. Apparently this precludes the use of fire, at least under natural conditions. Clearcutting on the Lewis and Clark National Forest in Montana (Anon. 1950) resulted in good regeneration of lodgepole pine both on the untreated forest floor and on the skid roads, with heavy slash inhibiting reproduction, and broadcast burning greatly curtailing it. Clearcutting in strips on the Kananaskis Forest Experiment Station, with piled slash, resulted in adequate but not superabundant regeneration (Crossley 1952), but success was credited to a poor site as reflected in a light surface litter and a scarcity of competing vegetation. Whether similar results could be obtained on better sites in Alberta where the duff is heavier than in Montana and where competition from more luxuriant ground vegetation becomes an important factor remained to be proved. Eyre and Lebarron (1944) were unable to regenerate jack pine adequately without baring the mineral soil to seed fall and they accomplished this by mechanical means. It is obvious when clearcutting in lodgepole pine stands that the seed to regenerate the site must come from one or both of the following sources: (1) from the serotinous cones in the slash, or (2) from the seed supply in the cones of the marginal stands. Contrary to the popularly accepted belief, not all lodgepole pine trees bear their cones serotinously, nor are all cones on any one tree necessarily serotinous. Studies presently under way in Alberta (Crossley 1955) indicate that there is a light but continuous seed release from natural pine stands which reaches a maximum at the time of cone ripening in September each year. The present study was designed to investigate the receptivity of the forest floor to lodgepole pine regeneration after strip clearcutting when mechanical scarification had bared the mineral soil, in comparison with the forest floor not specifically treated, each to be subjected to a seed supply from: (a) the marginal stands, and (b) marginal stands and the lopped and scattered slash.

◆ **Cushing, A. 2005.** The potential of lodgepole pine in Alaska . Unpubl. M.S. Thesis. Univ. of Alaska Fairbanks. 90 pp.

Author abstract. The introduction of non-native trees should be informed by various perspectives. In the case of forestry in high-latitude regions, managers face the challenge of finding cold-hardy species adequately adapted to harsh climatic environments; Lodgepole pine (Pinus contorta Dougl. Ex. Loud.) has been introduced to three regions at or above its natural northern latitudinal extent; Alaska, Iceland, and northern Sweden. Analysis of interviews in each region revealed the structure of common arguments, including underlying assumptions and perceptions of the natural world. Results of a mail-out-survey to the Alaskan public indicate that a considerable portion of the public is concerned about the possibility for adverse ecological effects on the native ecosystem. However, acceptance of non-native trees increased under certain circumstances; e.g. small-scale ornamental plantings, and when economic benefit is demonstrated. In comparisons of twenty-year growth data of lodgepole pine in Alaska with native white spruce (Picea glauca), lodgepole pine achieved greater height, diameter, and volume. The response of lodgepole pine in all three regions to scenarios of climate change was predicted using tree-ring analysis. Results indicate a negative response (reduced growth) in the Fairbanks area, a positive response (increased growth) in Delta and Glennallen, and a positive response at all but one Icelandic site and both Swedish sites. Overall, lodgepole pine appears relatively well-adapted to the present and modeled future environments of interior Alaska, Iceland, and northern Sweden.

◆ **Schrader, B. and P. Hennon (compilers). 2005.** Assessment of invasive species in Alaska and its national forests. Unpublished administrative paper. USDA Forest Service, Alaska Region, Juneau, Alaska. 26 p.

Author summary. This document assesses the current status of invasive species in Alaska's ecosystems, with emphasis on the State's two national forests. Lists of invasive species were developed in several taxonomic groups including plants, terrestrial and aquatic organisms, tree pathogens and insects. Sixty-three plant species have been ranked according to their invasive characteristics. Spotted knapweed, Japanese knotweed, reed canarygrass, white sweetclover, ornamental jewelweed, Canada thistle, bird vetch, orange hawkweed, and garlic mustard were among the highest-ranked species. A number of non-native terrestrial fauna species have been introduced or transplanted in Alaska. At this time only rats are considered to be causing substantial ecological harm. The impacts of non-native slugs in estuaries are unknown, and concern exists about the expansion of introduced elk populations in southeast Alaska. Northern pike represents the most immediate concern among aquatic species, but several other species (Atlantic salmon, Chinese mitten crab, and New Zealand mudsnail) could invade Alaska in the future. No tree pathogen is currently damaging Alaska's native tree species but several fungal species from Europe and Asia could cause considerable damage if introduced. Four introduced insects are currently established and causing defoliation and tree mortality to spruce, birch, and larch. The results of this assessment will be used to develop a strategy to manage invasive species by applying the principles of prevention, early detection, control, and rehabilitation in cooperation with different agencies and partners throughout Alaska.

◆ **Spellman, K.V. , C.P.H. Mulder, and T.N. Hollingsworth. 2014.** Susceptibility of burned black spruce (Picea mariana) forests to non-native plant invasions in interior Alaska. Publ. online Jan. 5, 2014. Biol. Invasions. DOI 10.1007/s10530-013-0633-6.

Author abstract. As climate rapidly warms at high-latitudes, the boreal forest faces the simultaneous threats of increasing invasive plant abundances and increasing area burned by wildfire. Highly flammable and widespread black spruce (Picea mariana) forest represents a boreal habitat that may be increasingly susceptible to non-native plant invasion. This study assess the role of burn severity, site moisture and time elapsed since burning in determining the invisibility of black spruce forests. We conducted field surveys for presence of non-native plants at 99 burned black spruce forest sites burned in 2004 in three regions of interior Alaska that spanned a gradient of burn severities and site moisture levels, and a chronosequence of sites in a single region that had burned in 1987, 1994, and 1999. We also conducted a greenhouse experiment where we grew invasive plants in vegetation and soil cores taken from a subset of these sites. In both our field survey and the greenhouse experiment, regional differences in soils and vegetation between burn complexes outweighed local burn severity or site moisture in determining the invisibility of burned black spruce sites. In the greenhouse experiments using cores from the 2004 burns, we found that the invasive focal species grew better in cores with soil and vegetation properties characteristic of low severity burns. Invasive plant growth in the greenhouse was greater in cores from the chronosequence burns with higher soil water holding capacity or lower native vascular biomass. We concluded that there are differences in susceptibility to non-native plant invasions between different regions of boreal Alaska based on native species regeneration. Reestablishment of native ground cover vegetation, including rapidly colonizing bryophytes, appear to offer burned areas a level of resistance to invasive plant establishment.

◆ **Villano, K.L. 2008.** Wildfire burn susceptibility to non-native plant invasions in black spruce forests of Interior Alaska. Unpubl. M.S. Thesis. Univ. of Alaska Fairbanks. 101 pp.

Author abstract. As the climate changes, Alaska's boreal forest faces the simultaneous threats of rising invasive plant abundances and increasing area burned by wildfire. Highly flammable and widespread black spruce forest represents a boreal habitat that may be increasingly susceptible to non-native plant invasion. In other biomes, non-native plant invasions are generally greatest in high severity burns that are only a few years old. The relationship between fire and non-native plant invasion has not been investigated in the northern boreal forest. To assess the invasibility of burned black spruce forests, I used burned field sites that spanned a gradient of burn severities, moisture levels, and burn ages. I conducted both field surveys and a greenhouse experiment using soil taken from burn sites. Contrary to generalizations from other biomes, I found soils from low severity burns and burns between 10 and 20 years old support greater invasive plant growth in black spruce forests than do high severity and more recent burns. In addition, regional differences between burn complexes outweighed burn severity and site moisture in determining the invasibility of burned black spruce sites. Finally, rebounding native vegetation appears to offer burned areas a level of resistance to invasive plant establishment.

CLIMATE CHANGE AND ASSISTED MIGRATION

◆ **Ager, T.A. 2001.** Holocene vegetation history of the northern Kenai Mountains, south-central Alaska. Pages 91-107 in Geologic studies in Alaska by the United States Geological Survey, 1999. L. Gough and R. Wilson (editors). United States Geological Survey, Professional Paper 1633. Denver, Colorado. 142 p.

Author abstract. Analysis of pollen assemblages from a 103-cm-thick peat deposit exposed near Tern Lake, Kenai Peninsula, Alaska, provides the first radiocarbon-dated postglacial vegetation history for the Kenai Mountains. The peat overlies glacial till deposited during the late Wisconsin glaciation. **A** peat sample from near the base of the deposit provides a radiocarbon age of 9,3 lot200 yr B.P., the first minimum age for deglaciation of the interior valleys of the Kenai Mountains. Earliest postglacial vegetation recorded at this site was composed of shrub birch (Betula nana), alder (Alnus), willow (Salix), grasses (Poaceae), wormwood (Artemisia), various herbs, and ferns (Polypodiaceae type). Another common shrub in this early postglacial vegetation was soapberry (Shepherdia canadensis), a shrub now uncommon on the Kenai Peninsula. Between about 8,600 and 7,800 yr B.P., soapberry shrubs were abundant in the area, along with ferns and alders. Soon after that, the alder population increased rapidly, soapberry shrubs diminished in importance, and boreal spruce (probably white spruce, Picea glauca) began to invade the western portals of the major valleys. The boreal spruce spread eastward into the mountain valleys from the northern Kenai Lowlands, probably along with paper birch trees (Betula papyrifera). By about 5,600 yr B.P., if not earlier, boreal spruce trees were colonizing the Tern Lake area. By about 2,900 yr B.P., small but significant amounts of pollen of mountain hemlock (Tsuga mertensiana) began appearing in the pollen assemblages at this site, and soon thereafter, spruce pollen percentages increased substantially. This rise in spruce and mountain hemlock pollen percentages probably reflects the colonization of the eastern and northern valleys of the Kenai Mountains by Sitka spruce (Picea sitchensis) and mountain hemlocks from sources in Prince William Sound to the east. The local vegetation seen in the Tern Lake area today developed within the past ca. 2,500 years. This vegetation is a rich mixture of boreal, (interior continental climate) and coastal-adapted (maritime climate) tree, shrub, and herb species. This blending of interior and coastal floras reflects a rather abrupt transitional boundary near Tern Lake between the maritime climate of the eastern and southern coasts of the Kenai Peninsula, and the more continental climate of the Kenai Lowland and northwestern Kenai Mountains. Many boreal plant species reach their easternmost range on the Kenai Peninsula near Tern Lake, and their further expansio

◆**Aitken, S.N., S. Yeaman, J.A. Holliday, T. Wang, S. Curtis-McLane. 2008.** Adaptation, migration or extirpation: climate change outcomes for tree populations. Evolutionary Applications **1**(1): 95-111.

Author abstract. Species distribution models predict a wholesale redistribution of trees in the next century, yet migratory responses necessary to spatially track climates far exceed maximum post-glacial rates. The extent to which populations will adapt will depend upon phenotypic variation, strength of selection, fecundity, interspecific competition, and biotic interactions.

Populations of temperate and boreal trees show moderate to strong clines in phenology and growth along temperature gradients, indicating substantial local adaptation. Traits involved in local adaptation appear to be the product of small effects of many genes, and the resulting genotypic redundancy combined with high fecundity may facilitate rapid local adaptation despite high gene flow. Gene flow with preadapted alleles from warmer climates may promote adaptation and migration at the leading edge, while populations at the rear will likely face extirpation. Widespread species with large populations and high fecundity are likely to persist and adapt, but will likely suffer adaptational lag for a few generations. As all tree species will be suffering lags, interspecific competition may weaken, facilitating persistence under suboptimal conditions. Species with small populations, fragmented ranges, low fecundity, or suffering declines due to introduced insects or diseases should be candidates for facilitated migration.

◆ **Alden, J.N. 1987**. Genetic diversity and population structure of picea glauca on an altitudinal gradient in Interior Alaska. Can. J. For. Res., 17(12): 1519-1526, 10.1139/x87-234.

Author abstract. Allozyme variation at 13 loci for 11 enzyme systems was studied in four white spruce (*Picea glauca* (Moench) Voss) populations extending from a floodplain at 120 m above sea level to the altitudinal tree limit at 750 m above sea level in interior Alaska. Although 97% of the total genetic diversity was among trees within stands and 1% was among stands within populations, frequencies of several allozymes and allozyme genotypes were significantly different ($P < 0.05$) among populations. Ninety-two percent of the loci were polymorphic. Total heterozygosity was 0.276. Heterozygosity and allozyme frequencies were not related to altitude. The population at the tree limit was as genetically diverse as populations at low elevations $(\bar{H}_e = 0.269)$ and contained four of seven rare alleles observed in all populations. These observations suggested that white spruce is genetically diverse in interior Alaska and the tree-limit population will continue to colonize new habitats. Genetic distance was not related to altitude and geographic distance and was less between the tree-limit and upper slope populations than among other populations. A detectable gene substitution rate was estimated at 10^{-6} per year. Populations on the upper slope and at the tree limit may have diverged about 2500 years ago and reached tree-limit altitudes only recently. Populations at low altitudes may have diverged during early Holocene white spruce expansion. We concluded that white spruce is genetically diverse in a small geographic area in interior Alaska. Results suggested that local white spruce populations should be regenerated from indigenous seed and that provenance research is needed to support afforestation programs.

◆ **Anderson, R.S., D.J. Hallett, E.E. Berg, R. B. Jass, J.L. Toney, C. S. De Fontaine, A. De Volder. 2006.** Holocene development of boreal forests and fire regimes on the Kenai Lowlands of Alaska. The Holocene 16(6):791-803.

Author description. Several studies have noted a relationship between vegetation type and fire frequency, yet despite the importance of ecosystem processes such as fire the long-term relationships between disturbance, climate and vegetation type are incompletely understood. We analysed pollen, plant macrofossils and sedimentary charcoal from three lakes within the Kenai lowlands to determine postglacial relationships between disturbance, climate and vegetation for the Boreal forest of southwest Alaska. An herb tundra was established in the lowlands following deglaciation by 13 000 cal. BP. Salix, Alnus and probably Betula kenaica, expanded in the area after 10 700 cal. BP, followed by Picea glauca by 8500 cal. BP. Picea mariana became established by 4600 cal. BP. The early Holocene was probably the driest time during the postglacial, as determined by aquatic plant macrofossils and climate models. Lake levels reached near-modern conditions by at least 8000 cal. BP. Mean Fire Intervals (MFI) were longest during the shrub-herb tundra phase (138+/-65 yr), decreased after expansion of B. kenaica, Salix and Populus (77+/-49 yr) and Picea glauca (81+/-41 yr), and increased again with the arrival of P. mariana (130+/-66 yr). Unlike previous studies, our data demonstrate the highest fire frequencies during the early to mid-Holocene and less frequent fire during the late Holocene when P. mariana forests dominated the lowlands. Early Holocene forests of P. glauca and B. kenaica existed in summers that were longer and drier than today, while the increasingly wetter and cooler climates of the late Holocene probably hindered forest fire around Paradox Lake, perhaps because of less frequent summer drought.

◆ **Barber, V.A., G.P. Juday, T. Osterkamp, R. D'Arrigo, E. Berg, B. Buckley, L. Hinzman, H. Huntington, T. Jorgensen, A.D. McGuire, B. Riordan, A. Whiting, G. Wiles, and M. Wilmking. 2009.** A synthesis of recent climate warming effects on terrestrial ecosystems in Alaska. Chapter 9 in Climate Warming in Western North America: Evidence and Environmental Effects (Edited by F. Wagner), pp. 110-139. University of Utah Press. Salt Lake City, Utah.

Author abstract. The instrument-based climate record in Alaska displays a strong late-twentieth century warming. Climate in Alaska also displays a record of sudden regime shifts. Precipitation there is highly variable and shows no strong trends. Effective moisture (P-PET), however, has decreased, resulting in widespread shrinkage and drying of lakes and ponds in the regions of low or moderate precipitation. Overall glacial mass balance is negative, and most show ice margin retreat, although some glacial systems are in positive mass balance. Permafrost is warming across the state, and ground subsidence associated with thawing of ice-rich permafrost is commonly observed. Since buildings and infrastructure, as well as natural disturbances, can cause warming of the permafrost, it is difficult to distinguish from climatic warming in some cases. The annual period of snow and ice cover is decreasing, and growing season is increasing in length with greater normalized difference vegetation index (NDVI) greenness in the tundra region. North of the Brooks Range, tall shrubs have advanced into the tundra, and warming experiments show that low shrub cover would significantly increase with additional warming. White spruce populations at treeline include trees that grow more with warming as well as others that grow less with warming. Major species in the boreal forest region also include populations with similar responses, but growth on many of the productive sites has declined. Recent high temperatures have caused widespread tree stress. Major outbreaks of tree-damaging insects have occurred due to both tree stress and direct temperature controls on insects. Millions of acres of beetle-killed trees on the Kenai Peninsula are a potential fire hazard. The extent of forest fires in Alaska is positively associated with specific temperature factors. These changes are confronting people with a variety of challenges, ranging from obtaining subsistence food and potable water to maintaining health and safety. Scenarios of future Alaska climate produced by general circulation models project significant future warming, which would exceed the apparent tolerance of some component species of current ecosystems.

◆ **Barber, V. A., G. P. Juday and E. Berg. 2002.** Assessment of recent and possible future forest responses to climate in boreal Alaska. Pages 102-105 plus 3 figures (pp 288-289) in Workshop on Northern Timberline Forests: Environmental and Socio-economic Issues and Concerns. Finnish Forest Research Institute. Kolari Research Station. 289 pp.

Val is checking for abstract

◆ **Barber, V.A., G.P. Juday, B.P. Finney and M. Wilmking. 2004.** Reconstruction of summer temperatures in interior Alaska from tree-ring proxies: evidence for changing synoptic climate regimes. Climatic Change 63:91-121.

Abstract. Maximum latewood density and δ13C discrimination of Interior Alaska white spruce were used to reconstruct summer (May through August) temperature at Fairbanks for the period 1800–1996, one of the first high-resolution reconstructions for this region. This combination of latewood density and δ13C discrimination explains 59.9% of the variance in summer temperature during the period of record 1906–1996. The 200-yr. reconstruction is characterized by 7 decadal-scale regimes. Regime changes are indicated at 1816, 1834, 1879, 1916, 1937, and 1974, are abrupt, and appear to be the result of synoptic scale climate changes. The mean of summer temperature for the period of reconstruction (1800–1996) was 13.49 ◦C. During the period of instrument record (1903–1996) the mean of summer temperature was 13.31 ◦C for both the reconstruction and the recorded data. The coldest interval was 1916–1937 (12.62 ◦C) and the warmest was 1974–1996 (14.23 ◦C) for the recorded data. The reconstruction differs from records of northern hemisphere temperatures over this period, especially because of Interior Alaska warm periods reconstructed from 1834 to 1851 (14.24 ◦C) and from 1862 to 1879 (14.19 ◦C) and because of the cool period in the early part of the 20th century (1917–1974). We show additional tree ring data that support our reconstruction of these warm periods. Alternate hypotheses involving autogenic effect of tree growth on the site, altered tree sensitivity, or novel combinations of temperature and precipitation were explored and while they cannot be ruled out as contributors to the anomalously warm 19th century reconstruction, they were not supported by available data. White spruce radial growth is highly correlated with reconstructed summer temperature, and temperature appears to be a reliable index of carbon uptake in this system.

◆ **Barber, V.A., G.P. Juday and B.P. Finney. 2000.** Reduced growth of Alaskan white spruce in the twentieth century from temperature-induced drought stress. Nature 405:668-673.

Author abstract. The extension of growing season at high northern latitudes seems increasingly clear from satellite observations of vegetation extent and duration1,2. This extension is also thought to explain the observed increase in amplitude of seasonal variations in atmospheric CO2 concentration. Increased plant respiration and photosynthesis both correlate well with increases in temperature this century and are therefore the most probable link

between the vegetation and CO2 observations3. From these observations1,2, it has been suggested that increases in temperature have stimulated as a whole4. Here we present multi-proxy tree-ring data (ring width, maximum late-wood density and carbon-isotope composition) from 20 productive stands of white spruce in the interior of Alaska. The tree-ring records show a strong and consistent relationship over the past 90 years and indicate that, in contrast with earlier predictions, radial growth has decreased with increasing temperature. Our data show that temperature-induced drought stress has disproportionately affected the most rapidly growing white spruce, suggesting that, under recent climate warming, drought may have been an important factor limiting carbon uptake in a large portion of the North American boreal forest. If this limitation in growth due to drought stress is sustained, the future capacity of northern latitudes to sequester carbon may be less than currently expected.

◆ **Barber, V.A. 2002.** Millennial to annual scale paleoclimatic change in central Alaska during the late quaternary interpreted from lake sediments and tree rings. Ph.D. Dissertation. University of Alaska Fairbanks. Fairbanks, AK, USA. 131 pp.

Author abstract: The theme of this dissertation is the importance of effective moisture (precipitation minus evaporation) in subarctic ecosystems. Interior Alaska has a relatively dry climate with annual precipitation ranging from 25-45 cm. Records from interior Alaska lake sediment cores show low lake levels following the Last Glacial Maximum, with significant increases at 12,000 and 9,000 14C years B.P. Using lake-level reconstructions and models based on modern hydrologic and meteorologic data, we infer precipitation of 35-75% less than modern at 12,000 yr. BP, 25-45% less than modern at 9,000 yr. BP, and 10-20% less than modern at 6,000 yr. BP. Trees were scarce on the interior Alaskan landscape during the late Pleistocene with birch species appearing about 12,000 BP and spruce species approximately 3500 years later. The correspondence between lake-level and vegetation changes suggests that moisture may have been one of the limiting factors in the establishment of these tree species. Alaska climate records show a climatic regime shift in the mid-1970s. Less effective moisture is available over the past 30 years because summer temperatures in interior Alaska have been increasing without a concurrent increase in precipitation. Radial growth of white spruce at 20 low elevation stands in interior Alaska declined corresponding with this climatic change. The observation that moisture limits spruce growth in Alaska today is consistent with our inference of moisture limitation in the early Holocene. A 200-year reconstruction was developed based on two tree ring proxies, 13C discrimination and maximum latewood density, which together show excellent agreement with the recorded Fairbanks average May through August temperatures. The first half of the 20th century is characterized by the coolest summers of the 200 year period of reconstruction, while the latter part of the 20th century, particularly from 1974 onward, is characterized by some of the warmest summers of the 200 year period. Mid-19th century summer temperatures reconstruct to be as warm as the latter part of the 20th century, which is inconsistent with reconstructions of other regions. It seems likely, based on current information, that these inconsistencies may be real and may reflect regional synoptic conditions unique to interior Alaska. Distinctive decadal scale regimes were identified throughout the record.

◆ **Beck, P.S.A., G.P. Juday, C. Alix, V.A. Barber, S.E. Winslow, E.E Sousa, P. Heiser, J.D. Herriges, S.J. Goetz. 2011.** Changes in forest productivity across Alaska consistent with biome shift. Ecology Letters 14(4): 373-379.

Author abstract: Global vegetation models predict that boreal forests are particularly sensitive to a biome shift during the 21st century. This shift would manifest itself first at the biome's margins, with evergreen forest expanding into current tundra while being replaced by grasslands or temperate forest at the biome's southern edge. We evaluated changes in forest productivity since 1982 across boreal Alaska by linking satellite estimates of primary productivity and a large tree-ring data set. Trends in both records show consistent growth increases at the boreal–tundra ecotones that contrast with drought-induced productivity declines throughout interior Alaska. These patterns support the hypothesized effects of an initiating biome shift. Ultimately, tree dispersal rates, habitat availability and the rate of future climate change, and how it changes disturbance regimes, are expected to determine where the boreal biome will undergo a gradual geographic range shift, and where a more rapid decline.

◆ **Berg, E.E., K.M. Hillman, R.Dial, A. DeRuwe. 2009.** Recent woody invasion of wetlands on the Kenai Peninsula Lowlands, south-central Alaska: a major regime shift after 18 000 years of wet *Sphagnum*–sedge peat recruitment. Canadian Journal of Forest Research, 2009, 39(11): 2033-2046, 10.1139/X09-121

Author abstract. We document accelerating invasion of woody vegetation into wetlands on the western Kenai Peninsula lowlands. Historical aerial photography for 11 wetland sites showed that herbaceous area shrank 6.2%/decade from 1951 to 1968, and 11.1%/decade from 1968 to 1996. Corresponding rates for converting herbaceous area to shrubland were 11.5% and 13.7%/decade, respectively, and, for converting nonforest to forest, were 7.8% and 8.3%/decade, respectively. Black spruce (Picea mariana (Mill.) BSP) forests on three wetland perimeters established since the Little Ice Age concluded in the 1850s. Dwarf birch shrubs at three wetland sites showed median apparent tree-ring age of 13 years, indicating recent shrub colonization at these sites. Peat cores at 24 wetland sites (basal peat ages 1840 – 18 740 calibrated years before present) indicated that these peatlands originated as wet Sphagnum–sedge fens with very little woody vegetation. Local meteorological records show a 55% decline in available water since 1968, of which one-third is due to higher summer temperatures and increased evapotranspiration and two-thirds is due to lower annual precipitation. These results suggest that wet *Sphagnum*–sedge fens initiating since the end of the Wisconsin glaciation began to dry in the 1850s and that this drying has greatly accelerated since the 1970s.

◆ **Cortini, F., P. G. Comeau, J. O. Boateng, L. Bedford, J. McClarnon, and A. Powelson. 2011.** Effects of climate on growth of lodgepole pine and white spruce following site preparation and its implications in a changing climate. Canadian Journal of Forest Research 41:180-194.

Author abstract. Site preparation and vegetation control can be used to mitigate climate change effects on early plantation growth in boreal forests. In this study, we explored growth of lodgepole pine (Pinus contorta Dougl. ex Loud. var. latifolia Engelm.) and white spruce (Picea glauca (Moench) Voss) in relation to climate and site preparation using 20 years of data collected from studies in British Columbia. Results indicate that up to 45% of the variation in spruce growth and up to 37% of the variation in pine growth over this 20-year period can be explained by selected climatic variables. Monthly climate variables showed a stronger relationship to conifer growth than seasonal and annual variables. Climate variables related to the preceding year accounted for more than half of the variables in the final equations, indicating a lagged response in conifer growth. Future projections indicated that height growth of young lodgepole pine plantations in the subboreal zone could benefit (in the short term) from longer growing seasons by up to 12% on untreated stands. Untreated young white spruce plantations in the boreal zone may suffer height growth decreases of up to 10% due to increased drought stress. Vegetation control and mechanical site preparation treatments appear to mitigate effects of climate change to some extent.

◆ **Danby, R. K. and HIK, D. S. 2007.** Responses of white spruce (*Picea glauca*) to experimental warming at a subarctic alpine treeline. Global Change Biology, 13: 437–451. doi: 10.1111/j.1365-2486.2006.01302.x

Author abstract. From 2001 to 2004 we experimentally warmed 40 large, naturally established, white spruce [*Picea glauca* (Moench) Voss] seedlings at alpine treeline in southwest Yukon, Canada, using passive open-top chambers (OTCs) distributed equally between opposing north and south-facing slopes. Our goal was to test the hypothesis that an increase in temperature consistent with global climate warming would elicit a positive growth response. OTCs increased growing season air temperatures by 1.8°C and annual growing degree-days by one-third. In response, warmed seedlings grew significantly taller and had higher photosynthetic rates compared with control seedlings. On the south aspect, soil temperatures averaged 1.0°C warmer and the snow-free period was nearly 1 month longer. These seedlings grew longer branches and wider annual rings than seedlings on the north aspect, but had reduced Photosystem-II efficiency and experienced higher winter needle mortality. The presence of OTCs tended to reduce winter dieback over the course of the experiment. These results indicate that climate warming will enhance vertical growth rates of young conifers, with implications for future changes to the structure and elevation of treeline contingent upon exposure-related differences. Our results suggest that the growth of seedlings on north-facing slopes is limited by low soil temperature in the presence of permafrost, while growth on south-facing slopes appears limited by winter desiccation and cold-induced photoinhibition.

◆ **Dial, R.J., E.E. Berg, K. Timm, A. McMahon, and J. Geck. 2007.** Changes in the alpine forest-tundra ecotone commensurate with recent warming in southcentral Alaska: evidence from othophotos and field plots. Journal of Geophysical Research, Volume 112, 15 p.

Author abstract. The complex response of the forest-tundra ecotone (FT) to climate change may not generalize well geographically. We document FT changes in a nonpermafrost region of southcentral Alaska during a known warming period. Using 1951 and 1996 orthophotos overlain on digital elevation models across 800 km^2 of the west Kenai Mountains, we identified cover classes and topography for 978 random points and the highest closed-canopy conifer patches along 205 random altitudinal gradients. Results show 29% of FT area increased in woodiness, with closed-canopy forest expanding 14%/decade and shrubs 4%/decade; unvegetated areas decreased 17.4%/decade and tundra 5%/decade. Area of open woodland remained constant but changed location. Timberline, estimated using both the 205 altitudinal gradients and the upper quartile elevations of closed-canopy forest among the 978 points, rose very little. Tree line, identified using upper quartiles of open woodland, rose ~50 m on cool, northerly aspects, but not on other aspects. Dendrochronology on high-elevation seedlings showed a congruence between decadal recruitment and regional changes in climate from 1945 to 2005. Patterns observed in the climatic FT of the Kenai Mountains corroborate other studies that show regional and landscape specificity of the structural response of FT to climate change. FT shifted upwards on cooler, presumably more mesic aspects near seed sources; however, on warm aspects the density of shrubs and trees increased, but FT did not rise. If current conditions continue for the next 50–100 years, the Kenai FT will markedly change to a far woodier landscape with less tundra and more closed-canopy forest.

◆ **Finkenbinder, M.S., M.B. Abbott, M.E. Edwards, C.T. Landon, B.A. Steinman, B.P. Phinney. 2014.** A 31,000 year record of paleoenvironmental and lake-level change from Harding Lake, Alaska. USA. Quat. Sci. Rev. 87 (2014) 98-113.

Author abstract: Physical and geochemical proxy analyses of sediment cores from Harding Lake in central Alaska are used to reconstruct paleoenvironmental change and millennial scale fluctuations in lake level for the last w31,000 years. We analyzed a composite 422 cm core from the lake depocenter (42.1 m water depth) and identified 4 distinct lithologic units based on variability in dry bulk density, organic matter, biogenic silica, carbon to nitrogen mass ratios (C/N), organic matter carbon isotopes (d13C), pollen, and elemental abundances via scanning X-ray fluorescence, with age control provided by 16 Accelerator Mass Spectrometry radiocarbon dates and 210Pb dating. In addition, we analyzed a transect of cores from 7.1 m, 10.75 m, 15.91 m, and 38.05 m water depths to identify lake level fluctuations and to characterize sediment compositional changes as a function of water depth. Organic matter content and magnetic susceptibility values in surface sediments from all transect cores show a strong correlation with water depth. Interpretation of four lithologic units with well-dated contacts produced a record of water-depth variations that is consistent with independent climate records from eastern Beringia. Basal coarse-grained sediments (quartz pebble diamicton) were deposited prior to 30,700 calendar years before present (yr BP), possibly from fluvial reworking or deflation during a period of severe aridity. Unit 1 sediments were deposited between 30,700 and 15,700 yr BP and are characterized by a low organic matter content, a high magnetic susceptibility, and low biogenic silica concentrations resulting from very low lake levels, low terrestrial and in-lake productivity and a high flux of clastic sediment. An abrupt increase in organic matter and biogenic silica concentration marks the transition into Unit 2 sediments, which were deposited between 15,700 and 9,400 yr BP when lake levels were higher and variable (relative to Unit 1). The transition to full interglacial conditions at 9,400 yr BP marks the beginning of Unit 3. Here an abrupt increase in the sedimentation rate, organic matter and biogenic silica concentration occurs (along with a corresponding decrease to low magnetic susceptibility). These high values persist until 8,700 yr BP, signifying a rapid rise to higher lake levels (in comparison to Units 1 and 2). Unit 4 sediments were deposited between 8,700 yr BP to 2010 AD and generally contain high concentrations of organic matter and biogenic silica with low magnetic susceptibility, suggesting that lake levels were relatively high and stable during the middle to late Holocene.

◆ **Fresco, N. 2012.** Chugach climate change scenarios project. Draft report. Scenarios Network for Alaska & Arctic Planning, University of Alaska, Fairbanks, Alaska. 25 pp.

Author introduction. Alaska is undergoing rapid changes. Substantial warming has occurred at high northern latitudes over the last half-century. Most climate models predict that high latitudes will experience a much larger rise in temperature than the rest of the globe over the coming century. At the same time, the state is undergoing rapid changes in human population and demands on natural resources. These changes mean that maintaining the status quo in operations and management of resources and growth may result in increased costs, risk, and resource damage. Future planning that accounts for these changes can avoid or reduce these potential liabilities.
For this project, the Scenarios Network for Alaska and Arctic Planning (SNAP: www/snap.uaf.edu), a program within the University of Alaska, provided objective scenarios based on climate projections and associated models of future landscape conditions. SNAP is a collaborative network that includes the University of Alaska, state, federal, and local agencies, NGO's, and industry partners. The SNAP network provides timely access to scenarios of future conditions in Alaska and other Arctic regions for more effective planning by communities, industry, and land managers. The network meets stakeholders' requests for specific information by applying new or existing research results, integrating and analyzing data, and communicating information and assumptions to stakeholders. SNAP's goal is to assist in informed decision-making.
The projections used in this project were for a range of modeled data, including a baseline time period (1971-2000), the current decade (10's), and future decades (20's, 40's, and 60's). These data provided measurements of change as they are likely to manifest themselves in and around the Chugach National Forest. SNAP provided data on the effects of climate change on the following environmental factors: mean and extreme July and January temperature; mean and extreme July and January precipitation; timing of thaw and freeze; length of unfrozen season; and estimated snowline. In addition, SNAP provided information from the published literature regarding other potential climate-linked changes, including those associated with the Pacific Decadal Oscillation (PDO), ocean acidification, and storm frequency and intensity.

◆ **Gauthier, S., P. Bernier, P.J. Burton, J. Edwards, K. Isaac, N. Isabel, K. Jayen, H. Le Goff, E.A. Nelson. 2014.** Climate change vulnerability and adaptation in the managed Canadian boreal forest. Environmental Reviews, 10.1139/er-2013-0064.

Author abstract. Climate change is affecting Canada's boreal zone, which includes most of the country's managed forests. The impacts of climate change in this zone are expected to be pervasive and will require adaptation of Canada's forest management system. This paper reviews potential climate change adaptation actions and strategies for the forest management system, considering current and projected climate change impacts and their related vulnerabilities. These impacts and vulnerabilities include regional increases in disturbance rates, regional changes in forest productivity, increased variability in timber supply, decreased socioeconomic resilience, and increased severity of safety and health issues for forest communities. Potential climate change adaptation actions of the forest management system are categorized as those that reduce nonclimatic stressors, those that reduce sensitivity to climate change, or those that maintain or enhance adaptive capacity in the biophysical and human subsystems of the forest management system. Efficient adaptation of the forest management system will revolve around the inclusion of risk management in planning processes, the selection of robust, diversified, and no-regret adaptation actions, and the adoption of an adaptive management framework. Monitoring is highlighted as a no-regret action that is central to the implementation of adaptive forest management.\

◆ **Gundale M.J., P. Kardol, M-C. Nilsson, U. Nilsson, R.W. Lucas, D.A. Wardle. 2014.** Interactions with soil biota shift from negative to positive when a tree species is moved outside its native range. New Phytologist; DOI: 10.1111/nph.12699

Author abstract: Studies evaluating plant–soil biota interactions in both native and introduced plant ranges are rare, and thus far have lacked robust experimental designs to account for several potential confounding factors.

- Here, we investigated the effects of soil biota on growth of *Pinus contorta*, which has been introduced from Canada to Sweden. Using Swedish and Canadian soils, we conducted two glasshouse experiments. The first experiment utilized unsterilized soil from each country, with a full-factorial cross of soil origin, tree provenance, and fertilizer addition. The second experiment utilized gamma-irradiated sterile soil from each country, with a full-factorial cross of soil origin, soil biota inoculation treatments, tree provenance, and fertilizer addition.
- The first experiment showed higher seedling growth on Swedish soil relative to Canadian soil. The second experiment showed this effect was due to differences in soil biotic communities between the two countries, and occurred independently of all other experimental factors.
- Our results provide strong evidence that plant interactions with soil biota can shift from negative to positive following introduction to a new region, and are relevant for understanding the success of some exotic forest plantations, and invasive and range-expanding native species.

◆ **Hamrick, J. L. 2004**. Response of forest trees to global environmental changes. Forest Ecology and Management **197**:323-335.

Author abstract: Characteristics of tree species may uniquely situate them to withstand environmental changes. Paleoecological evidence indicates that the geographic ranges of tree species have expanded and contracted several times since the last glacial epoch in response to directional environmental changes. For most tree species, these range fluctuations have been accomplished without any apparent loss of genetic diversity. A possible explanation that distinguishes most trees from many herbaceous plants is that much of the genetic variation within tree species is found within rather than among their populations. Thus, the extinction of a relatively large proportion of a tree species' populations would result in relatively little overall loss of genetic diversity. Furthermore, phylogeographic studies indicate that for some tree species, habitat heterogeneity (elevation, slope aspect, moisture, etc.) in glacial refugia may have preserved adaptive genetic variation that, when recombined and exposed to selection in newly colonized habitats, gave rise to the local adaptation currently seen.

The maintenance of genetic diversity in the face of extensive habitat fragmentation is also a concern. Many forest trees, however, may be buffered from the adverse effects of habitat fragmentation. First, the longevity of individual trees may retard population extinction and allow individuals and populations to survive until habitat recovery occurs. Second, considerable evidence is available that both animal and wind-pollinated tree species in fragments experience levels of pollen flow that are sufficient to counteract the effects of genetic drift. The combination of individual longevity, high intra-population genetic diversity and the potential for high rates of pollen flow should make tree species especially resistant to extinction and the loss of genetic diversity during changing environmental conditions.

◆ **Hogg, E.H. and R.W. Wein. 2005.** Impacts of drought on forest growth and regeneration following fire in southwestern Yukon, Canada. CJFR. 35(9): 2141-2150, 10.1139/x05-120**.**

Author abstract. The valleys of southwestern Yukon have a continental climate with average annual precipitation of <300 mm. In 1958, fires burned large areas of mature mixed wood forests dominated by white spruce (*Picea glauca* (Moench) Voss) in the valleys near Whitehorse. Since then, the burned areas have shown poor regeneration of spruce, but have been colonized by scattered clones of trembling aspen (*Populus tremuloides* Michx.) interspersed by grassland. The objective of the study was to examine the influence of climatic variation on forest growth and regeneration in the 1958 burn and the adjacent unburned forests. Tree-ring analysis was conducted on 50 aspen and 54 white spruce in 12 mature stands where these species were codominant, and on 147 regenerating aspen in the 1958 Takhini burn. The mature stands were uneven-aged and the patterns of growth variation for the aspen and spruce between 1944 and 2000 were similar. Growth of both species was most strongly related to variation in precipitation. The regenerating aspen had a wide age-class distribution (1959–2000) and their growth was also positively related to precipitation. The results indicate that these forests have been slow to regenerate after fire, and are vulnerable if the climate becomes drier under future global change.

◆ **Johnston, M., S. Webber, G.A. O'Neill, T. Williamson, and K. Hirsch. 2009.** Climate change impacts and adaptation strategies for the forest sector in Canada. In 2nd Climate Change Technology Conference, 12-15 May, 2009. Hamilton, ON. Engineering Institute of Canada.

Author abstract: Impacts on forests will vary regionally across Canada, with continental interior locations likely to experience greater extremes in temperature and precipitation. At the species level there will be short-term physiological responses to climate variability and long-term genetic responses to future climate change. Trees that are adapted to the climate at the time of establishment may be considerably maladapted to the climate at harvest time, displaying reduced productivity and increased frequency of pest attack. Although our ability to pro-actively mitigate possible short-term impacts to current climate change is limited, we have the opportunity to assist species and populations with migration to climatically-suitable habitats. This is a management activity called “assisted migration”, and represents an important forest management activity to mitigate the negative consequences of climate change. Other possible management interventions to assist the adaptation of tree species include; improved tree breeding, altered silviculture activities, shorter rotation periods, use of exotics and fast-growing species. [PDF 373 kb]

◆ **Juday, G.P., V. Barber, E. Berg and D. Valentine. 1999**. Recent dynamics of white spruce treeline forests across Alaska in relation to climate. Pages 165-187 in S. Kankaanpaa, T. Tasanen and M.-L. Sutinen, editors. Sustainable development in northern timberline forests. Proceedings of the Timberline Workshop. The Finnish Forest Research Institute, Ministry of the Environment, Finland.

Author summary. (1) Treelines in Alaska show a strong response to the climate warming since the mid-19th century end of the Little Ice Age. The population structure of treeline white spruce in the central Alaska Range and southcentral coastal mountain regions is consistent with steady upslope recruitment of spruce in a warming climate since the mid 1800s. White spruce established since the Little Ice Age at the northwestern Alaska tree limit may be growing faster than spruce established earlier in colder conditions.

(2) White spruce at latitudinal and upper elevation treeline in Alaska are generally vigorous and have been able to reproduce steadily or at least at periodic intervals since the beginning of the 20th century or earlier. Particular years with favorable weather for triggering white spruce cone crops include 1912, 1915, 1926, and especially 1940. Many of the well established treeline trees of today at central Alaska treelines may date from the 1940 or 1941 seed crop.

(3) A low elevation treeline in contact with grassland occurs in the dry central interior portion of Alaska. If recent warming and drying trends there persist or intensify, direct and indirect effects of moisture stress could result in white spruce retreat and expansion of grassland or aspen parkland.

(4) Strong climate warming has occurred widely across Alaska, especially since 1976. Some locations, such as the central Brooks Range have experienced increased summer temperatures and increased summer precipitation. An index of moisture stress composed of summer temperature and annual precipitation at Fairbanks records sustained, high levels of moisture stress since 1976.

(5) Only a small proportion of treeline spruce in the in the mountains of southcentral Alaska are sensitive to summer temperature. The actual elevational limit for growth of spruce in the mountains of southcentral Alaska may be substantially higher than the current elevation of established trees.

◆ **Juday, G.P., V. Barber, S. Rupp, J. Zasada, M.W. Wilmking. 2003.** A 200-year perspective of climate variability and the response of white spruce in Interior Alaska. In: Greenland, D., D. Goodin, and R. Smith (eds.). Climate Variability and Ecosystem Response at Long-Term Ecological Research (LTER) Sites. Oxford University Press. Chapter 12 Pp. 226-250.

Compiler summary. This publication documents ecological responses in white spruce related to climate variability at Bonanza Creek. The long time series allows the identification of repeated outcomes, including changes in climate, tree growth, seed crop timing and abundance, and stand age cohort parameters.

This study analyzes the impact of El Niño years on seed crops and burned acreage. Strong and moderate El Niños generally produce positive temperature anomalies in Interior Alaska but generally below normal precipitation, particularly in the winter (Hess et al. 2001, Ropelewski and Halpert 1986).

Some treeline populations of white spruce in Alaska no longer respond to increased warmth (Jacoby et al. 1999). Juday et al. 1999 demonstrated that Alaska treelines respond in different ways to recent climate warming, depending on the location and environmental setting of the treeline. Under some scenarios, changing temperature sensitivity could become a widespread phenomenon, and treeline climate reconstructions should be viewed with caution.

The key cue of environmental variability for white spruce is a critical period of warm and dry early summer weather in successive years, which generates strong stress (Owens and Mulder 1977). These same dry weather conditions represent fire weather (Johnson et al. 1992). It appears that the described reproductive timing of white spruce maximizes the odds that seeds will be released into a landscape in which fires have occurred recently, and the thick organic mat of the forest floor is reduced or removed. A disproportionate share of the living young white spruce trees less than 50 years in Interior Alaska are the result of reproduction in 1958, 1970, 1987, 1998. On average only about 14 major reproductive events occur during the life of a white spruce stand.

◆ **Juday, G.P., V. Barber, E. Vaganov, S. Rupp, S. Sparrow, J. Yarie, H. Linderholm, E. Berg, R. D'Arrigo, P. Duffy, O. Eggertsson, V.V. Furyaev, E.H. Hogg, S. Huttunen, G. Jacoby, V.Ya. Kaplunov, S. Kellomaki, A.V. Kirdyanov, C.E. Lewis, S. Linder, M.M. Naurzbaev, F.I. Pleshikov, Yu.V. Savva, O.V. Sidorova, V.D. Stakanov, N.M. Tchebakova, E.N. Valendik, E.F. Vedrova, and M. Wilmking. 2005.** Forests, Land Management, Agriculture. In Arctic Climate Impact Assessment, Arctic Council, Cambridge University Press, pages 781-862.

Compiler summary. This publication synthesizes information on forest, land management, and agriculture interactions with climate change and carbon storage across the boreal region in North America, Scandinavia, and Russia.

Tree growth and warm- season temperature have irregularly decreased in northernmost Eurasia and North America from the end of the postglacial thermal maximum through the end of the 20th century. Long-term tree-ring chronologies from Russia, Scandinavia, and North America record the widespread occurrence of a Medieval Warm Period about 1000 years BP, a colder Little Ice Age ending about 150 years ago, and more recent warming. Recent decades were the warmest in a millennium or more at some locations. Temperature and tree growth records generally change at the same time and in the same direction across much of the Arctic and subarctic.

The record of past forest advances suggests that there is a solid basis for projecting similar treeline change under climate change producing similar temperature increases. It also suggests that the components of ecosystems present today have the capacity to respond and adjust to such climate fluctuations. In northeast Canada, recent milder winters have permitted stems that were restricted to snow height by cold and snow abrasion to emerge in upright form, and future climate projected by the ACIA-designated models would permit viable seed production, which is likely to result in infilling of the patchy forest–tundra border and possibly begin seed rain onto the tundra. In the Polar Ural Mountains, larch reproduction is associated with warm weather, and newly established trees have measurably expanded forest cover during the 20th century.

Across the boreal forest, warmer temperatures in the last several decades have affected tree growth, depending on species, site type, and region. Temperature-induced drought stress has been identified as the cause of reduced growth in some areas, but other declines are not currently explained. Reduced growth in years with high temperatures is common in treeline white spruce in western North America, suggesting reduced potential for treeline movement under a warming climate. Tree growth is increasing in some locations, generally where moisture and nutrients are not limiting, such as in the boreal regions of Europe and eastern North America. The five ACIA-designated models project climates that empirical relationships suggest are very unlikely to allow the growth of commercially valuable white spruce types and widespread black spruce types in major parts of Alaska and probably western boreal Canada. The upper range of the model projections represents climates that may cross ecological thresholds, and it is possible that novel ecosystems could result, as during major periods of global climate change in the past.

Large-scale forest fires and outbreaks of tree-killing insects are characteristic of the boreal forest, are triggered by warm weather. Climate change effects on disturbance include a greater frequency of fire or insect outbreaks, more extensive areas of tree mortality, and more intense disturbance resulting in higher average levels of tree death or severity of burning.

Different crop species and even varieties of the same species can exhibit substantial variability in sensitivity to ultraviolet-B (UV-B) radiation. In susceptible plants, UV-B radiation causes gross disruption of photosynthesis, and may inhibit plant cell division. Damage by UV-B radiation is likely to accumulate over the years in trees. Evergreens receive a uniquely high UV radiation dose in the late winter, early spring, and at the beginning of the growing season because they retain leaves during this period when exposure is amplified by reflectance from snow cover. Exposure to enhanced levels of UV-B radiation induces changes in the anatomy of needles on mature Scots pine similar to characteristics that enhance drought resistance. UV-B radiation plays an important role in the formation of secondary chemicals in birch trees at higher latitudes. Secondary plant chemicals released by birch exposed to increased UV-B radiation levels might stimulate its herbivore resistance.

◆ **Juday, G.P., T. Grant III, and D.L. Spencer. 2012.** Boreal Alaska aspen growth rate collapse and mortality from high temperatures, drought, and insect attack. Presentation to: Ecol. Soc. of America annual meeting. Aug. 10, 2012.

Compiler summary. The authors measured tree disks from 117 aspens trees in seven stands across central and eastern Interior Alaska. Tree disk data were compared to mean monthly temperature and monthly total precipitation data from Fairbanks from 1912 through 2011.

The authors reported that warm summer temperatures were a negative predictor of growth, and precipitation in specific months was a positive predictor. From the mid-1970s through the 1990s, strongly unfavorable climate index values were associated with a major growth reduction. A sustained leaf miner outbreak further reduced growth.

◆ **Juday, G.P., R.A. Ott, D.W. Valentine and V.A. Barber. 1998.** Forests, climate stress, insects, and fire. Pp. 23-49 in G. Weller, and P. Anderson, editors. Implications of global change in Alaska and the Bering Sea region. Center for Global Change and Arctic System Research, University of Alaska Fairbanks, Fairbanks, Alaska, USA.

Compiler summary. The authors identify numerous potential changes in the Alaska boreal forest under projected climate change scenarios and summarize them according to confidence and degree of impact. Potential changes affecting reforestation include:
• A period of widespread insect-caused mortality and severe/extensive forest fires across interior and southcentral Alaska would occur.
• Earlier onset of plant growth in the spring and prolonged growing seasons in the fall (“shoulder seasons”) will deepen the regional moisture deficit at low elevation forest sites. The Tanana and Yukon Valleys will become more like the aspen parkland typical of Edmonton, Alberta.
• Aspen, birch, and tamarack forests would experience more frequent and widespread defoliation by insects, including the large aspen tortrix (*Choristoneura conflictana*), spear-marked black moth (*Rheumaptera hastata*), birch leaf roller (*Epinotia solandriana*), larch sawfly (*Pristiphora erichsonii*), and bronze birch borer (*Agrilus anxius*).
• Forest regeneration failure and drought-induced tree mortality on low-elevation south slopes would occur, followed by grassland expansion.
• Forest expansion into tundra would occur westward on the Seward Peninsula.
• Forest expansion into tundra would occur upward in elevation in a relatively limited zone in the Brooks Range, Alaska Range, Chugach Mountains, and Yukon-Tanana Uplands.
• Following the fires, there would be a shortage of white spruce seed for regeneration because of unfavorable climate, population reduction, and tree isolation. Newly regenerating forests will be composed of greater proportions of aspen, birch, grassland, and shrubland than the current landscape.
• Fire frequency would increase in general, and the average fire return interval in any given forest landscape will be decreased. More frequent fires will help maintain grassland against forest recolonization.
• White spruce cone crops will be produced less frequently because of sustained periods of warm and dry weather.

The authors also identify research needs and recommend mitigation measures including
• Design and fund a forest regeneration program to enhance or supplement forest responses to global warming effects. Prepare to plant increased amounts of local seed sources of white spruce and to supplement it on managed or salvage logged sites. Launch a tree improvement program to find the best adapted genotypes of white spruce in a changing environment.

• Reduce the number of trees in overstocked managed stands to reflect lower actual carrying capacity in new higher-stress environments. Manage more carefully to avoid creating dense stagnant stands that could serve as local initiation points for widespread tree-damaging insect outbreaks.
• Promote a diverse mix of tree and other plant species.

◆ **Juday, G.P., R.A. Ott, D.W. Valentine and V.A. Barber. 1997.** Assessment of actual and potential global warming effects on forests of Alaska. Pages 121-126 in New England Regional Climate Change Impacts Workshop. Institute for the Study of Earth, Oceans, and Space, University of New Hampshire, Durham, New Hampshire, USA.

Compiler summary. This paper summarizes climate warming and drying trends in coastal and boreal forests in Alaska over the last 20 years, and describes the current and potential impacts of these changes.

Key points related to boreal forests include:

- Warm early spring and summer weather is apparently a necessary trigger factor in the production of the infrequent excellent white spruce cone and seed crops (Alden 1985, Zasada et al 1992). Until recently the occurrence of a high number of days with warm temperatures in the early summer would be followed predictably the following year by a white spruce cone crop, unless a crop was already being produced in the trigger year. In the last decade or more, greater numbers of warm days than ever have occurred but crops are not being formed.
- Annual precipitation and summer precipitation have decreased during the entire period of record in Fairbanks (1906-96). Summer precipitation has decreased at rate of 17% per century at Fairbanks.
- White spruce growth is positively related to precipitation and negatively related to temperature. White spruce trees on productive sites near Fairbanks have become moisture stressed due to longer growing seasons. Treeline trees that were previously limited only by warmth, are now limited by moisture stress (Jacoby and D'Arrigo, 1995).
- Continued warming and drying would interfere with reproduction of white spruce. Warming of the interior Alaska climate without a sufficient increase in precipitation that was effective in supplying water to the forest in the driest part of the year (mid and late summer) would probably transform large areas of productive lowland boreal
- Future climate change could increase damage from defoliators and tree-boring insects that have previously had outbreaks in Alaska, and from insect species that have not been produced landscape-level effects on Alaska's forests in the recent past.
- The likelihood of a transition period of large fires in the Alaskan boreal forest is substantial, because overall area burned is well correlated with the average summer temperature, and large areas of standing dead forest provide fuel that would be difficult to keep from burning once ignited. The fire potential following a transition period of large fires is less certain. The new landscape probably would support a fewer conifer stands and more hardwood stands that would be relatively fire-resistant.

- If reproduction of desired species is not certain in the future, forest management plans may need to be adjusted today. Artificial tree regeneration can help mitigate this problem, but costs and other land management objectives must be addressed.

◆ **Keller S.R., R.Y. Soolanayakanahally, R.D. Guy, S.N. Silim, M.S. Olson, Tiffin. 2011.** Climate-driven local adaptation of ecophysiology and phenology in balsam poplar, Populus balsamifera L. (Salicaceae). American Journal of Botany 98(1): 99-108.

Author abstract: During past episodes of climate change, many plant species experienced large-scale range expansions. Expanding populations likely encountered strong selection as they colonized new environments. In this study we examine the extent to which populations of the widespread forest tree Populus balsamifera L. have become locally adapted as the species expanded into its current range since the last glaciation.

We tested for adaptive variation in 13 ecophysiology and phenology traits on clonally propagated genotypes originating from a range-wide sample of 20 subpopulations. The hypothesis of local adaption was tested by comparing among-population variation at ecologically important traits (Q(ST)) to expected variation based on demographic history (F(ST)) estimated from a large set of nuclear single nucleotide polymorphism loci.

Evidence for divergence in excess of neutral expectations was present for eight of 13 traits. Bud phenology, petiole length, and leaf nitrogen showed the greatest divergence (all Q(ST) > 0.6), whereas traits related to leaf water usage showed the least (all Q(ST) ≤ 0.30) and were not different from neutrality. Strong correlations were present between traits, geography, and climate, and they revealed a general pattern of northern subpopulations adapted to shorter, drier growing seasons compared with populations in the center or eastern regions of the range.

Our study demonstrates pronounced adaptive variation in ecophysiology and phenology among balsam poplar populations. These results suggest that as this widespread forest tree species expanded its range since the end of the last glacial maximum, it evolved rapidly in response to geographically variable selection.

◆ **Kranabetter, J.M., M.U. Stoehr, and G.A. O'Neill. 2012.** Divergence in ectomycorrhizal communities with foreign Douglas-fir populations and implications for assisted migration. Ecological Applications 22(2):550-560

Author abstract. Assisted migration of forest trees has been widely proposed as a climate change adaptation strategy, but moving tree populations to match anticipated future climates may disrupt the geographically based, coevolved association suggested to exist between host trees and ectomycorrhizal fungal (EMF) communities. We explored this issue by examining the consistency of EMF communities among populations of 40 year-old Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) trees in a common-garden field trial using four provenances from contrasting coastal climates in southwestern British Columbia. Considerable variation in EMF community composition within test sites was found, ranging from 0.38 to 0.65 in the mean similarity index, and the divergence in EMF communities from local populations increased with site productivity. Clinal patterns in colonization success were detected for generalist and specialist EMF species on only the two productive test sites. Host population effects were limited to EMF species abundance rather than species loss, as richness per site averaged 15.0 among provenances and did not differ by transfer extent (up to 450 km), while Shannon's diversity index declined slightly. Large differences in colonization rates of specialist fungi, such as *Tomentella stuposa* and *Clavulina cristata*, raise the possibility that EMF communities maladapted to soil conditions contributed to the inferior growth of some host populations on productive sites. The results of the study suggest locally based specificity in host–fungal communities is likely a contributing factor in the outcome of provenance trials, and should be a consideration in analyzing seed-transfer effects and developing strategies for assisted migration. [Link]

◆ **Leech, S.M., P.L. Almuedo, and G. O'Neill. 2011.** Assisted Migration: Adapting forest management to a changing climate. BC Journal of Ecosystems and Management 12(3):18-34.

Author abstract: Forestry practitioners are increasingly interested in how to adapt practices to accommodate predicted changes in climate. One forest management option involves helping tree species and seed sources (populations) track the movement of their climates through "assisted migration": the purposeful movement of species to facilitate or mimic natural population or range expansion. In this paper, we discuss assisted migration as a climate change adaptation strategy within forest management. Substantial evidence suggests that most tree species will not be able to adapt through natural selection or migrate naturally at rates sufficient to keep pace with climate change, leaving forests susceptible to forest health risks and reduced productivity. We argue that assisted migration is a prudent, proactive, inexpensive strategy that exploits finely tuned plant-climate adaptations wrought through millennia of natural selection to help maintain forest resilience, health and productivity in a changing climate. Seed migration distances being considered in operational forestry in British Columbia are much shorter than migration distances being contemplated in many conservation biology efforts and are informed by decades of field provenance testing. Further, only migrations between similar biogeoclimatic units are under discussion. These factors reduce considerably the risk of ecological disturbance associated with assisted migration. To facilitate the discussion of assisted migration, we present three forms of assisted migration, and discuss how assisted migration is being considered internationally, nationally, and provincially. Finally, we summarize policy and research needs and provide links to other resources for further reading. [PDF 303 kb]

◆ **Lev, D.J. 1987.** Balsam poplar (Populus balsamifera) in Alaska : ecology and growth response to climate. Unpubl. M.S. Thesis, University of Washington, Seattle. 70 p.

Author introduction (excerpt). Balsam poplar *(Populus balsamifera)* grows farther north than any other tree species in Alaska and in some areas also defines the alpine limit of trees {Viereck and Little, 1972; Edwards and Dunwiddie, 1985). The species survives flooding on low elevation river terraces and can be found in the driest parts of the state. Balsam poplar is the first t:ree to colonize newly exposed river gravel and was the f:!rst tree species to gain importance in northern Alaska after retreat of the late-Wisconsin glaciers. Yet little research has .been done on this remarkable species.

This study examines balsam poplar's ecology and growth response to climate at three different locations in Alaska: the Brooks Range, Alaska Range and Interior Lowland. The species' response to climate is used to help interpret Paleoecological conditions and to infer phenology at these sites. Since poplar stands of Alaska's interior floodplains have been described (Viereck, 1970), the site description and vegetation analysis parts of this study focus on the tree limit locations in the Brooks Range and Alaska Range.

Stands of balsam poplar at the alpine limits of trees are particularly interesting since the species usually occurs as a colonizer of floodplain sites in the boreal forest (Zasada and Phipps, 1983). The species does possess several traits that explain its appearance at tree limit. With its ability to reproduce from root sprouts, an individual balsam poplar can maintain itself through long periods of hostile climate conditions (Barnes, 1966). Isolated, catastrophic events that destroy an entire stand of individuals may stimulate root sprouting *to* replace poplars. Since poplar is deciduous, it is not subject to severe winter desiccation described for treeline conifers, where warm spring temperatures encourage transpiration through leaves while water uptake by roots is prevented in still frozen ground (Tranquiliini, 1963, 1976).

Isolated stands of poplar in the-Brooks Range have also sparked the interest of paleo-ecologists who search for modern analogs to past vegetation. Palynological studies in northern Alaska and northwestern Canada have shown a peak in poplar pollen of up to 40% during the period of 11,000 to 9,000years B.P. (Cwyner, 1982; Ritchie, 1984; Ager and Brubaker;1985) Ritchie *eta/.* (1983) interpret the *Populus* peak as an indication of an early Holocene warm period. According to the Milankovitch theory of climate change, at 9,000 years B.P. the earth was closest to the sun during northern hemisphere summer, creating warm arctic growing seasons (Ritchie *et al.,* 1983).

Dendroclimatic studies generally relate annual tree growth to monthly or annual climatic data summaries but short arctic growing seasons may call for finer temporal resolution. In this study, climatic data from Alaskan weather stations have been summarized by five-day periods. Results of the analyses using monthly and five-day climatic summaries are compared. The climate-growth analysis is also used to infer and compare phenology at the three different locations. The results of this study suggest that phenological inference from tree-rings may be a useful tool for evaluating populations in remote areas where continual observation is not possible.

◆ **Okano, K. 2012.** Growth Response of White Spruce [Picea glauca (Moench) Voss] in Denali National Park under Warming Climate. Poster URI:http://hdl.handle.net/11122/1559

Author abstract. In subarctic mountains such as Denali National Park and Preserve(DNP), vegetation shifts from alpine tundra to boreal forests caused by recent climate change are a potential threat to plant conservation and indirectly to animal habits and diversity, which could affect the experience of visitors who wish to see wildlife.• The growth rate of Picea glauca (white spruce) could decrease by climate change due to drought stress, which might lead to species elimination.• The shift of P. glauca towards a higher elevation would require its

seedlings not only to adapt to new abiotic harsh conditions, but also to compete with other plant species that are already present.

◆ **O'Neill, G.A., N.K. Ukrainetz, M.R. Carlson, C.V. Cartwright, B.C. Jaquish, J.N. King, J. Krakowski, J.H. Russell, M.U. Stoehr, C-Y. Xie, and A.D. Yanchuk. 2008.** Assisted migration to address climate change in British Columbia: recommendations for interim seed transfer standards. B.C. Min. For. Range, Res. Br., Victoria, B.C. Tech. Rep. 048.

Author abstract: Columbia becoming increasingly maladapted to the climates in which they are planted. Consequently, planting seedlings adapted to future climates (assisted migration) is recognized as a key strategy to address climate change, as it will help maintain healthy, productive forests, and ensure capture of gains obtained from decades of selective breeding.

To examine opportunities to incorporate assisted migration into British Columbia's seed transfer system, the feasibility of increasing the upper elevational transfer limit of British Columbia's Class A and Class B seed was assessed by calculating the climatic transfer distance associated with elevational transfers. A rationale was developed for quantifying an appropriate climatic distance and range to migrate seed, and was used to evaluate elevational transfer increases of 100 and 200 m.

Results indicate that of the 30 Class A Seed Planning Units (spus) examined, eight should retain their current upper elevation limits, one should have its upper elevation limit increased by 100 m, and the remainder should have their upper elevation limits increased by 200 m. Upper elevation transfer limits of Class B seed should be increased by 200 m for eight species, by 100 m for two species, and should remain unchanged for three species. Specific recommendations are provided in Tables 2 and 3.

Deployment of orchard seed in the lowest 200 m of the western white pine—Maritime and interior spruce—East Kootenay spus is discouraged, as is transfer of Class B seed of amabilis fir and western hemlock more than 200 m downward and western redcedar more than 300 m downward. [PDF 6286 kb]

◆ **O'Neill, G.A., M.R. Carlson, V. Berger, and A.D. Yanchuk. 2007**. Responding to climate change: assisting seedlot migration to maximize adaptation of future forest plantations. Ticktalk 8: 9-12.

Author abstract: Little is currently known regarding the adaptive responses of breeding populations of BC's commercially important tree species. To ensure that each reforestation site receives the Class A seedlots that are best adapted and most productive for its current and future climate, each breeding/ production population must be tested across a broad range of climatic and latitudinal environments. The Assisted Migration Adaptation Trial (AMAT) intends to test the 35 breeding/ production populations (i.e., Class A seed orchard seedlots for which seed is available, from BC and western States) across 48 test sites. Twelve field tests per year for each of four years will be established throughout BC and neighbouring states, beginning in spring 2009. Use of local control (wild stand) seedlots and a block plot layout will enable realized genetic gains to be estimated for each population. Productivity of each population will be described as a function of the climate and latitude of the test sites, enabling development of a deployment system that will maximize forest productivity while ensuring the widest deployability of every orchard seedlot. [PDF 510 kb]

◆ **Pedlar, J.H., D.W. McKenney, I. Aubin, T. Beardmore, J. Beaulieu, L. Iverson, G.A. O'Neill, R.S. Winder, and C. Ste-Marie. 2012.** Placing Forestry in the Assisted Migration Debate. Bioscience 62(9):835-842

Author abstract. Assisted migration (AM) is often presented as a strategy to save species that are imminently threatened by rapid climate change. This conception of AM, which has generated considerable controversy, typically proposes the movement of narrowly distributed, threatened species to suitable sites beyond their current range limits. However, existing North American forestry operations present an opportunity to practice AM on a larger scale, across millions of hectares, with a focus on moving populations of widely distributed, nonthreatened tree species within their current range limits. Despite these differences (and many others detailed herein), these two conceptions of AM have not been clearly distinguished in the literature, which has added confusion to recent dialogue and debate. Here, we aim to facilitate clearer communication on this topic by detailing this distinction and encouraging a more nuanced view of AM. [Link]

◆ **Pedlar, J., D. McKenney, J. Beaulieu, S. Colombo, J. McLachlan, and G. O'Neill. 2011.** The implementation of assisted migration in Canadian forests. For. Chron. 87(6):766-777

Author abstract. We outline the major steps involved in implementing assisted migration (AM) and assess, in a general way, the capacity to carry out each step in Canadian forests. Our findings highlight the fact that capacity to implement AM differs between forest species; in particular, the existence of established provenance trials, seed transfer guidelines, seed procurement systems, and plantation establishment protocols makes AM considerably more feasible for most commercial tree species than for most species of conservation concern. We report on several AM efforts involving commercial tree species that are already underway in Canada and identify a number of initiatives that could be undertaken to help build AM capacity. This paper is not intended as an endorsement of the AM approach; however, we feel there is considerable value in discussing implementation issues at this point in the AM debate. [Link]

◆ Peterson, D.L., C.I. Millar, L.A. Joyce, M.J. Furniss, J.E. Halofsky, R.P. Neilson, and T.L. Morelli. 2011. Responding to climate change in national forests: a guidebook for developing adaptation options. USDA Forest Service, Pacific Northwest Research Station, General Technical Report. PNW-GTR-855. Portland, Oregon. 109 p.

Author abstract. This guidebook contains science-based principles, processes, and tools necessary to assist with developing adaptation options for national forest lands. The adaptation process is based on partnerships between local resource managers and scientists who work collaboratively to understand potential climate change effects, identify important resource issues, and develop management options that can capitalize on new opportunities and reduce deleterious effects. Because management objectives and sensitivity of resources to climate change differ among national forests, appropriate processes and tools for developing adaptation options may also differ. Regardless of specific processes and tools, the following steps are recommended: (1) become aware of basic climate change science and integrate that understanding with knowledge of local resource conditions and issues (review), (2) evaluate sensitivity of specific natural resources to climate change (rank), (3) develop and implement strategic and tactical options for adapting resources to climate change (resolve), and (4) monitor the effectiveness of adaptation options (observe) and adjust management as needed. Results of recent case studies on adaptation in national forests and national parks can facilitate integration of climate change in resource management and planning and make the adaptation process more efficient. Adaptation to climate change will be successful only if it can be fully implemented in established planning processes and other operational aspects of national forest management.

◆ **Price, D.T., R.I. Alfaro, K.J. Brown, M.D. Flannigan, R.A. Fleming, E.H. Hogg, M.P. Girardin, T. Lakusta, M. Johnston, D.W. McKenney, J.H. Pedlar, T. Stratton, R.N. Sturrock, I.D. Thompson,[c] J.A. Trofymow, L.A. Venier**. **2013.** Anticipating the consequences of climate change for Canada's boreal forest ecosystems. Environmental Reviews. 21(4): 322-365, 10.1139/er-2013-0042.

Author abstract. Canadian boreal woodlands and forests cover approximately 3.09 × 10^6 km^2, located within a larger boreal zone characterized by cool summers and long cold winters. Warming since the 1850s, increases in annual mean temperature of at least 2 °C between 2000 and 2050 are highly probable. Annual mean temperatures across the Canadian boreal zone could be 4–5 °C warmer than today's by 2100. All aspects of boreal forest ecosystem function are likely to be affected. Further, several potential "tipping elements" — where exposure to increasing changes in climate may trigger distinct shifts in ecosystem state — can be identified across the Canadian boreal zone. Approximately 40% of the forested area is underlain by permafrost, some of which is already degrading irreversibly, triggering a process of forest decline and re-establishment lasting several decades, while also releasing significant quantities of greenhouse gases that will amplify the future global warming trend. Warmer temperatures coupled with significant changes in the distribution and timing of annual precipitation are likely to cause serious tree-killing droughts in the west; east of the Great Lakes, however, where precipitation is generally nonlimiting, warming coupled with increasing atmospheric carbon dioxide may stimulate higher forest productivity. Large wildfires, which can cause serious economic losses, are expected to become more frequent, but increases in mean annual area burned will be relatively gradual. The most immediate threats could come from endemic forest insect pests that have the potential for population outbreaks in response to relatively small temperature increases. Quantifying the multiple effects of climate change will be challenging, particularly because there are great uncertainties attached to possible interactions among them, as well as with other land-use pressures. Considerable ingenuity will be needed from forest managers and scientists to address the formidable challenges posed by climate change to boreal ecosystems and develop effective strategies to adapt sustainable forest management practices to the impending changes.

◆ **Robertson A.L. 2012.** Acclimation and migration potential of balsam poplar, Populus balsamifera L., in a changing climate. Unpublished Univ. of Alaska Fairbanks PhD thesis.

Author abstract. In the North American boreal forest, 21st century climate change is projected to result in longer growing seasons, increased forest productivity, and northward expansions or shifts in species ranges. These projected impacts are largely based on observations across natural temperature gradients, e.g., latitude or altitude, or correlations between current species' distributions and modern climate envelopes. These approaches, although valuable, do not consider biological capacities important in a species' ability to cope with novel environments through physiological or phenological acclimation. Within a single species, adaptation to local environments may cause some populations to respond differently to climate change than others. Acclimation (phenotypic plasticity) is often treated as a separate phenomenon from local adaptation, but the latter may determine the range of acclimation responses or thresholds. To more accurately predict how boreal tree species will respond to a directionally changing climate, it is necessary to experimentally examine the effects of warming on the growth and physiology of individual species and how those effects differ across a species' range. This research investigated how tree growth responses to increasing temperature are influenced by differences in adaptation and acclimation across the latitudinal range of the North American boreal forest tree, Populus balsamifera L. (balsam poplar). Warming experiments, both in the greenhouse and in the field, indicated that growth of balsam poplar trees from a broad latitudinal gradient responds positively to increased growing temperatures, with increases in height growth ranging from 27-69 % in response to 3-8 °C average warming. Genotypes from southern populations grew consistently taller in both field and greenhouse experiments. The field experiment enabled investigation into the effects of warming and source latitude on balsam poplar phenology; both experimentally warmed and southern individuals grew larger and exhibited longer growing seasons (more days of active growth). Lastly, I describe a theoretical/methodological framework for exploring the role of epigenetics in acclimation (plasticity) and adaptation to changing environments. The results from these experiments are integrated with information on adaptive gradients in balsam poplar to predict both the in situ responses of balsam poplar to increased temperatures, and the potential for northward range shifts in the species.

◆ **Roland, C.A., J.H. Schmidt, and J.F. Johnstone. 2013.** Climate sensitivity of reproduction in a mast-seeding boreal conifer across its distributional range from lowland to treeline forests. Oecologia. Published online Nov. 10, 2013. The final publication is available at link.springer.com

Author abstract: Mast-seeding conifers such as *Picea glauca* exhibit synchronous production of large seed crops over wide areas, suggesting climate factors as possible triggers for episodic high seed production. Rapidly changing climatic conditions may thus alter the tempo and spatial pattern of masting of dominant species with potentially far-reaching ecological consequences. Understanding the future reproductive dynamics of ecosystems including boreal forests, which may be dominated by mast-seeding species, requires identifying the specific cues that drive variation in reproductive output across landscape gradients and among years. Here we used annual data collected at three sites spanning an elevation gradient in interior Alaska, USA between 1986 and 2011 to produce the first quantitative models for climate controls over both seedfall and seed viability in *P. glauca*, a dominant boreal conifer. We identified positive associations between seedfall and increased summer precipitation and decreased summer warmth in all years except for the year prior to seedfall. Seed viability showed a contrasting response, with positive correlations to summer warmth in all years analyzed except for one, and an especially positive response to warm and wet conditions in the seedfall year. Finally, we found substantial reductions in reproductive potential of *P. glauca* at high elevation due to significantly reduced seed viability there. Our results indicate that major variation in the reproductive potential of this species may occur in different landscape positions in response to warming, with decreasing reproductive success in areas prone to drought stress contrasted with increasing success in higher elevation areas currently limited by cool summer temperatures.

◆ **Roland, C.A., J.H. Schmidt, and E.F. Nicklen. 2013**. Landscape-scale patterns in tree occupancy and abundance in subarctic Alaska. Ecol. Monographs. 83(1) 19-48.

Author abstract. Recent studies suggest that climate warming in interior Alaska may result in major shifts from spruce-dominated forests to broadleaf-dominated forests or even grasslands. To quantify patterns in tree distribution and abundance and to investigate the potential for changes in forest dynamics through time, we initiated a spatially extensive vegetation monitoring program covering 1.28 million ha in Denali National Park and Preserve (DNPP). Using a probabilistic sampling design, we collected field measurements throughout the study area to develop spatially explicit Bayesian hierarchical models of tree occupancy and abundance. These models demonstrated a strong partitioning of the landscape among the six tree species in DNPP, and allowed us to account for and examine residual spatial autocorrelation in our data. Tree distributions were governed by two primary ecological gradients: (1) the gradient from low elevation, poorly drained, permafrost-influenced sites with shallow active layers and low soil pH (dominated by Picea mariana) to deeply thawed and more productive sites at mid-elevation with higher soil pH on mineral substrate (dominated by Picea glauca); and (2) the gradient from older, less recently disturbed sites dominated by conifers to those recently affected by disturbance in the form of fire and flooding with increased occupancy and abundance of broadleaf species. We found that the establishment of broadleaf species was largely dependent on disturbance, and mixed forests and pure stands of broadleaf trees were relatively rare and occurred in localized areas. Contrary to recent work in nearby areas of interior Alaska, our results suggest that P. glauca distribution may actually increase in DNPP under warming conditions rather than decline as previously predicted, as P. glauca expands into areas formerly underlain by permafrost. We found no evidence of a shift to broadleaf forests in DNPP, particularly in the poorly drained basin landscape positions that may be resistant to such changes. Overall, our results indicate that probabilistic sampling conducted at a landscape scale can improve inference relative to the habitat associations driving the distribution and abundance of trees in the boreal forest and the potential effects of climate change on them.

◆ **Rowland, E.L. 1997.** The recent history of treeline at the northwest limit of white spruce in Alaska . Unpubl. M.S. Thesis. Univ. of Alaska Fairbanks. 129 pp.

Author abstract. To understand how the northwestern-most treeline in Alaska has responded to changes in climate since the 19th century, I investigated the history and autecology of white spruce in two tributaries valleys of the Noatak River. A pollen record from Loon Lake extends back to ca. 6,000 years B.P. and indicates that spruce was growing around the mouth of the Kelly River (the middle Noatak Valley} by at least 1 ,900 years ago. Data collected from white spruce stands in the Kelly and Kugururok River valleys suggest that treeline in these areas became established within the last 600 years. Although the rate of recruitment in the spruce stands has been fairly steady throughout the last three centuries, recruitment did increase between A 0. 1920 and 1950 in response to the Northern Hemisphere temperature maximum. This response is evidenced by increased density in white spruce stands in valley bottoms and by the upslope movement of the altitudinal limit of spruce. The data from the study areas in the Kelly and Kugururok River valleys indicate that white spruce treeline has not extended beyond its current limit during the last 300 years.

◆ **Sanders, T. 2011.** Adaptive management in response to climate change: a synthesis of research findings and observations from the Pacific Northwest Forest. World Forest Institute, Portland, OR. 48 pp.

Author abstract. Temperature in the Pacific Northwest region (PNW) has warmed 0.7-0.9 ◦C since 1920 and is expected to increase further by the end of the century. Projected changes in regional precipitation are less certain than those for temperature. Overall, small decreases in summer precipitation and small increases in winter precipitation are predicted. Increases in greenhouse gas concentrations, especially CO_2, are contributing to the warming of the atmosphere.

Elevated CO_2 will impact forests both directly and indirectly. Tree growth, reproduction, and mortality are affected via the direct effects on the physiological processes of photosynthesis, respiration, and transpiration. Increased temperatures are expected to impact both the growth and regeneration stages of populations, whilst increases in the frequency of heavy precipitation events may increase the incidence of flood-related injuries.

Climate change can affect both the frequency and severity of disturbances that play a vital role in the natural dynamics of forests in the PNW. Events such as wildfires, insect outbreaks, diseases, droughts, windstorms and landslides profoundly influence ecosystem dynamics in terms of ecosystem structure, composition, and functioning.

Climate change will require trees to cope with new climatic and biotic environments. Populations of trees may cope with new climates by 1) adapting to new conditions in their current location (acclimate), 2) migrating to new locations, or 3) evolving in place (*in situ* evolution). If they cannot cope, they may disappear from local ecosystems altogether (extinction).

Silvicultural and genetic practices may be employed to assist in forest adaptation to climate changes, principally by influencing stand structure and species composition throughout stand development. The four management steps of review, rank, resolve and observe, considered iteratively, is an effective process for facilitating adaptation. Two case studies are used to illustrate how scientific research and land management agencies can cooperate to develop and implement adaptation options for assisting forest ecosystems to adjust to rapid climate change. The first describes adaptation strategies being used in the Olympic National Forest from a silvicultural perspective. The second is in the field of forest genetics, and refers to the Assisted Migration Adaptation Trial (AMAT) being conducted in parts of British Columbia, and the states of Washington, Oregon, Idaho and Montana.

Barriers to adaptation include limited financial and human resources, policies that do not recognize climate change as a significant issue, and lack of an official science–management partnership. Information and tools needed to assist adaptation to climate can change hinge on this type of partnership.

Ten key strategies are highlighted as worthy of pursuing, and warranting further investigation in their potential for application in native forest management in Victoria, Australia. It is essential that dynamic and adaptive thinking is integrated into the way we make planning and management decisions, including our learning from changing conditions.

◆ **Tape, K. 2011.** Arctic Alaskan shrub growth, distribution, and relationships to landscape processes and climate during the 20th century. Unpubl. PhD thesis. Univ. of Alaska Fairbanks. 137 pp.

Author abstract. The primary change underway in the tundra of Arctic Alaska is the increase in air temperature and expansion of deciduous shrubs since 1980. I explored relationships between shrub expansion and relevant ecosystem properties such as climate, soil characteristics, erosion, and herbivory. Alnus viridis ssp. fruticosa (Siberian alder) shrubs located along streams, rock outcrops, or other features with active disturbance regimes showed a positive correlation between growth ring widths and March through July air temperature. Climate-growth relationships were much weaker for alder in adjacent tussock tundra. Additionally, tussock tundra sites had different vegetation composition, shallower thaw, lower mean annual ground temperature, lower mean growing season temperature, higher soil moisture, more carbon in mineral soil, and higher C:N values in shrub leaves than nearby non-tussock alder. Growth rings and site characteristics imply that preexisting soil conditions predispose alder shrubs growing in non-tussock tundra to respond rapidly to warming. Analysis of temporal series of aerial photography from 1950 and 2000 and of Landsat imagery from 1986 and 2009 showed an increase in percent cover of shrubs, primarily in riparian areas. This increase in shrubs is contemporaneous with a decline in peak discharge events from the Kuparuk River and a lengthening of the growing season since 1980, both of which may have caused the decline in sediment deposition observed in 3 of 4 lake sediment cores dated with lead and cesium isotopes. Both alder shrub growth and erosion are particularly sensitive to runoff dynamics during the snowmelt and green-up period, and these dynamics are affected by spring temperatures. Ptarmigan, moose, and hares forage heavily on shrubs protruding above the deepening snow during the late-winter, and selective browsing on willow vs. alder is likely influencing shrub community composition. The increase in shrubs during the 20th century may represent additional habitat for these herbivores, and herbivore-mediated changes in shrub architecture may have important implications for how shrubs trap snow and ultimately affect surface energy balance. Evidence from this thesis indicates shrub growth and cover have increased in response to persistent warming, particularly in areas where the organic layer is thinner and active layer deeper.

◆ **Ukrainetz, N.K., G.A. O'Neill, and B. Jaquish. 2011**. Comparison of fixed and focal point seed transfer systems for reforestation and assisted migration: a case study for interior spruce in British Columbia. Can. J. For. Res. 41(7):1452-1464.

Author abstract. In forestry, science-based seed transfer systems, the foundation of effective reforestation programs, will likely be used in some form to mitigate the negative effects of climate change. In this study, we developed fixed and focal point seed transfer systems for interior spruce (*Picea glauca* (Moench) Voss, *Picea engelmannii* Parry ex Engelm., and their hybrids) in British Columbia, Canada, and compared the effectiveness of both systems. Growth, phenology, and physiology traits were measured for 112 populations, and population means were transformed to principal components that were modeled using climate variables and multiple regression analysis. Compared with the fixed seed zone system, the focal point system had a greater area of seed use for a given risk of maladaptation. The relationship between growth and adaptive distance (i.e., adaptive similarity between test populations and populations local to test sites) was used to calculate critical seed transfer distances for focal point seed zones, which were defined according to expected forfeiture of growth. Changes in climate observed over the past 100 years and predicted in the next one third of a rotation were used to calculate appropriate assisted migration distances and develop methods for incorporating assisted migration into a focal point seed transfer system. [Link]

◆ **Van Cleve, K., W.C. Oechel, and J.L. Hom 1990.** Response of black spruce (picea mariana) ecosystems to soil temperature modification in interior Alaska . *Canadian Journal of Forest Research*, 1990, 20(9): 1530-1535, 10.1139/x90-203

Author abstract. This paper reports results of a study designed to examine the control that soil temperature exerts on soil processes associated with nutrient flux, and in turn, on tree nutrition in interior Alaska black spruce ecosystems. Approximately 50 m^2 of forest floor in a 140-year-old black spruce ecosystem, which had developed on permafrost, was heated to 8–10 °C above ambient temperature. This perturbation amounted to approximately a 1589 degree-day seasonal heat sum (above 0 °C), 1026 degree-days above the control total of 563 degree-days. The forest floor, surface 5 cm of mineral soil, and soil solution were compared with those of an adjacent control plot to evaluate the change in nutrient content and decomposition rate of the forest floor. The nutritional response to soil heating of current black spruce foliage also was evaluated. Soil heating significantly increased decomposition of the forest floor, principally because of an increase in biomass loss of the O21 layer. The increased decomposition resulted in greater extractable N and P concentrations in the forest floor, higher N concentrations in the soil solution, and elevated spruce needle N, P, and K concentrations for the experimental period. These results are discussed in light of the importance of soil temperature and other state factors that mediate ecosystem function.

◆ **Walker, X., and J.F. Johnstone. 2014.** Widespread negative correlations between black spruce growth and temperature across topographic moisture gradients in the boreal forest Environ. Res. Lett. 9: 064016 (9pp)

Author abstract. The responses of tree growth to recent climate warming may signal changes in the susceptibility of forest communities to compositional change and consequently impact a wide range of ecosystem processes and services. Previous research in the boreal forest has largely documented negative growth responses to climate in forest species and habitats characteristic of drier conditions, emphasizing the sensitivity of drier or warmer landscape positions to climate warming. In this study, we explored relationships between climate and tree-ring growth of black spruce, a dominant tree species typical of cool and moist habitats in the boreal forests of North America. We assessed how these responses varied with stand characteristics and landscape position across four different regions in Alaska and Yukon Territory. Approximately half of the trees measured across regions and topographic gradients exhibited reduced radial growth in response to warm temperatures in the previous growing season and current spring, which we interpret as a signal of drought stress. Although we found considerable variation in the growth responses of individual trees within sites, landscape position and stand characteristics were weak predictors of this variability, explaining ≤12% of the variation in any region. Our results indicate that future warming, particularly in spring, is likely to result in drought stress and a reduction of black spruce radial growth independent of region, landscape position, or stand characteristics. The occurrence of negative growth responses to temperature, even in cool and moist habitats, suggests that drought stress limitations may be more widespread in the northern boreal forest than previously anticipated, indicating broad sensitivity of ecosystem processes and services to climate change across a diverse range of habitat types.

◆ **Wang, T., E.M. Campbell, G.A. O'Neill, and S.N. Aitken. 2012**. Projecting future distributions of ecosystem climate niches: Uncertainties and management applications. For. Ecol. Manage. 279:128-140

Author abstract. Projecting future distributions of ecosystems or species climate niches has widely been used to assess the potential impacts of climate change. However, variability in such projections for the future periods, particularly the variability arising from uncertain future climates, remains a critical challenge for incorporating these projections into climate change adaptation strategies. We combined the use of a robust statistical modeling technique with a simple consensus approach consolidating projected outcomes for multiple climate change scenarios, and exemplify how the results could guide reforestation planning. Random Forest (RF) was used to model relationships between climate (1961–1990), described by 44 variables, and the geographic distribution of 16 major ecosystem types in British Columbia (BC), Canada. The model predicted current ecosystem distributions with high accuracy (mismatch rate = 4–16% for most ecosystem classes). It was then used to predict the distribution of ecosystem climate niches for the last decade (2001–2009) and project future distributions for 20 climate change scenarios. We found that geographic distributions of the suitable climate habitats for BC ecosystems have already shifted in 23% of BC since the 1970s. Consensus projections for future periods (2020s, 2050s, 2080s) indicated climates suitable for grasslands, dry forests, and moist continental cedar–hemlock forests would substantially expand; climate habitat for coastal rainforests would remain relatively stable; and habitat for boreal, subalpine and alpine ecosystems would decrease substantially. Using these consensus projections and data on the occurrence of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) in BC ecosystems, we estimated a twofold increase in seedling demand for this frost-sensitive, commercially important timber species, suggesting managers could begin planning to expand seed inventories and seed orchard capacity to more widely plant this species on logged sites. The results of this work demonstrate the power of RF for building climate envelope models and illustrate the utility of consensus projections for incorporating uncertainty about future climate into management planning. It also emphasizes the immediate need for adapting natural resource management to a changing climate. [Link]

◆ **Wendler G., M. Shulski**. **2009**. A century of climate change for Fairbanks, Alaska. Arctic 62(3): 295-300.

Author abstract: Climatological observations are available for Fairbanks, Interior Alaska, for up to 100 years. This is a unique data set for Alaska, insofar as it is of relatively high quality and without major breaks. Applying the best linear fit, we conclude that the mean annual temperature rose from -3.6˚C to -2.2˚Cover the century, an increase of 1.4˚C (compared to 0.8˚C worldwide). This comparison clearly demonstrates the well-known amplification or temperature change for the polar regions. The observed temperature increase is neither uniform over the time period nor uniform throughout the course of a year. The winter, spring, and summer seasons showed a temperature increase, while autumn showed a slight decrease in temperature. For many activities, the frequencies of extremes are more important than the average values. For example, the frequency of very low temperatures (below -40˚C, or -40˚F) has decreased substantially, while the frequency of very high temperatures (above 26.7˚C, or 80˚F) increased only slightly. Finally, the length of the growing season increased substantially (by 45%) as a result of an earlier start in spring and a later first frost in autumn. Precipitation decreased for Fairbanks. This is a somewhat counter-intuitive result, as warmer air can hold more water vapor. The date of the establishment of the permanent snow cover in autumn showed little change; however, the melting of the snow cover now occurs earlier in the spring, a finding in agreement with the seasonal temperature trends. The records for wind, atmospheric pressure, humidity, and cloudiness are shorter, more broken, or of lower quality. The observed increase in cloudiness and the decreasing trend for atmospheric pressure in winter are related to more advection and warmer temperatures during this season.

◆ **Williamson, T.B.; S.J. Colombo, P.N. Duinker, P.A. Gray, P.A, R.J. Hennessey, D. Houle, M.H. Johnston, A.E. Ogden, D.L. Spittlehouse. 2009.** Climate change and Canada's forests: from impacts to adaptation. Sustain. For. Manag. Netw. and Nat. Resour. Can., Can. For. Serv., North. For. Cent., Edmonton, AB. 104 p.

Author abstract: Climate change is already affecting Canada's forests. Current visible effects include changes in the frequency and severity of disturbances (such as fires, drought, severe storms, and damaging insect and disease attacks): other less visible changes such as change in the timing of spring bud burst are also underway. One of the consequences of future climate change will be further increases in the frequency and severity of extreme weather events and disturbances. Changes in productivity, species composition, and age- class distribution are also expected. Moisture and temperature are key factors affecting productivity. Productivity is likely to decrease in areas that are now or will become drier; productivity is expected to increase (at least in the near term) in northern areas that are currently limited by cold temperatures. An important consideration, however, is that genotypes tend to be finely adapted to local climates and potential productivity gains may not be realized if forest managers don't match genotypes to suitable climates. A higher percentage of the forests will be in younger age classes, and the frequency of early succession species and species adapted to disturbance will increase. Climatically suitable habitats for most species will move northward and will increase in elevation but the actual movement of species will lag behind the rate of movement of climatic niches. Climate change has implications for both current and future timber supply. The net impact of climate change on timber supply will vary from location to location. The recent mountain pine beetle event shows that climate-related factors can have dramatic effects on timber supply in a relatively short time period. Climate change will impact harvest operations. A significant portion of the harvest in Canada occurs in the winter when the ground is frozen. Harvesting on frozen ground allows for access to wetlands, reduces soil disturbance, and decreases costs of delivered wood. The magnitudes of change in climate that will be faced by Canada's forests and forest management sector and the consequent scale of expected impacts have no historical analogue. Canada's forest sector will need to adapt and it will need to do so without the benefit of prior experience. Forest managers can expect the unexpected and they can expect that change will be ongoing and unrelenting. Some general recommendations for beginning to address climate change in Canada's forest sector include enhancing the capacity to undertake integrated assessment of vulnerabilities to climate change at various scales; increasing resources to monitor the impacts of climate change; increasing resources for impacts and adaptation science; reviewing forest policies, forest planning, forest management approaches, and institutions to assess our ability to achieve social objectives under climate change; embedding principles of risk management and adaptive management into forest management; and maintaining or improving the capacity for communicating, networking, and information sharing with the Canadian public and within the forest sector.

◆ **Wilmking, M., G.P. Juday, V. Barber, and H. Zald. 2004.** Recent climate warming forces **contrasting** growth responses of white spruce at treeline in Alaska through temperature thresholds. Global Change Biology 10:1-13.

Author abstract. Northern and high-latitude alpine treelines are generally thought to be limited by available warmth. Most studies of tree-growth–climate interaction at treeline as well as climate reconstructions using dendrochronology report positive growth response of treeline trees to warmer temperatures. However, population-wide responses of treeline trees to climate remain largely unexamined. We systematically sampled 1558 white spruce at 13 treeline sites in the Brooks Range and Alaska Range. Our findings of both positive and negative growth responses to climate warming at treeline challenge the widespread assumption that arctic treeline trees grow better with warming climate. High mean temperatures in July decreased the growth of 40% of white spruce at treeline areas in Alaska, whereas warm springs enhance growth of additional 36% of trees and 24% show no significant correlation with climate. Even though these opposing growth responses are present in all sampled sites, their relative proportion varies between sites and there is no overall clear relationship between growth response and landscape position within a site. Growth increases and decreases appear in our sample above specific temperature index values (temperature thresholds), which occurred more frequently in the late 20th century. Contrary to previous findings, temperature explained more variability in radial growth after 1950. Without accounting for these opposite responses and temperature thresholds, climate reconstructions based on ring width will miscalibrate past climate, and biogeochemical and dynamic vegetation models will overestimate carbon uptake and treeline advance under future warming scenarios.

◆ **Wilmking M., Juday G.P., Terwilliger M., Barber V. 2006.** Modeling spatial variability of white spruce (Picea glauca) growth responses to climate change at and below treeline in Alaska - A case study from two National Parks. Erdkunde 60 (2):113-126.

Author abstract: Aim of this study was to develop a spatially explicit, medium-scale model of the climate sensitivity of recent white spruce growth at and below treeline in Denali National Park (DNP) and Gates of the Arctic National Park (GAAR) in Alaska and then use the model to project changes in extent of boreal forest under future warming scenarios. We developed a decision tree model to examine tree growth-environment relationships and used a GIS to extrapolate model results into space. In DNP our results indicate possible dieback of white spruce at low elevations and treeline advance and infilling at high elevations. If recent warming continues, the road corridor in DNP would experience forest increase of about 50%, mainly along the road decreasing the possibility for visitors to observe wildlife across open tundra. In GAAR our results indicate increased rate of white spruce growth at low elevation areas while other areas would experience changes in forest structure (dieback of tree-islands, infilling of existing stands). Changes in distribution of white spruce forests in Alaska are within the range of possibility on a regional scale (treeline advance, dieback). Structural changes within existing forest are possible on a medium (landscape) scale through changes in tree density, infilling and dieback. Changes in growth performance of individual trees due to climate warming are already underway, and further warming would intensify these changes with landscape-wide consequences.

◆ **Wolken, J.J. and T.N. Hollingsworth. 2012.** Alaska. Pages 205-209 (Appendix I: Regional Summaries, Alaska) in Effects of climatic variability and change on forest ecosystems: a comprehensive science synthesis for the U.S. forest sector. J.M. Vose, D.L Peterson, and T. Patel-Weynand (editors). USDA Forest Service, Pacific Northwest Research Station, General Technical Report PNW-GTR-870. Portland, Oregon. 265 p.

Author excerpt. Interior Alaska: In interior Alaska, the most important biophysical factors responding to changes in climate are permafrost thaw and changes in fire regime. The region is characterized by discontinuous permafrost, defined as ground (soil or rock) that remains at or below 0 °C for at least 2 years (Harris et al. 1988). Thawing permafrost may substantially alter surface hydrology, resulting in poorly drained wetlands and thaw lakes (Smith et al. 2005) or well-drained ecosystems on substrates with better drainage. Permafrost thaw may occur directly as a result of changes in regional and global climate, but it is particularly significant following disturbance to the organic soil layer by wildfire (fig. A1-2). As permafrost thaws, large pools of stored carbon (C) in frozen ground are susceptible to increased decomposition, which will have not only regional effects on gross primary productivity (Vogel et al. 2009) and species composition (Schuur et al. 2007) but also feedbacks to the global C system (Schuur et al. 2008). The observed warmer air and permafrost temperatures have important societal impacts, because transportation, water and sewer, and other public infrastructures may be damaged (Larsen et al. 2008, Nelson et al. 2002). Recent changes in the fire regime in interior Alaska are linked to climate. The annual area burned in the interior has doubled in the last decade compared to any decade since 1970, with three of the largest wildfire years on record (fig. A1-2) also occurring during this time (Kasischke et al. 2010). Black spruce forests, the dominant forest type in the interior, historically burned in low-severity, stand-replacing fires every 70 to 130 years (Johnstone et al. 2010a). However, postfire succession of black spruce (*Picea mariana* [Mill.] Britton, Sterns & Poggenb.) forests has recently shifted toward deciduous-dominated forests with the increase in wildfire severity (Johnstone and Chapin 2006, Johnstone and Kasischke 2005, Kasischke and Johnstone 2005) and the reduction in fire-return interval (Bernhardt et al. 2011; Johnstone et al. 2010a, 2010b). With continued warming, changes in the fire regime will increase the risk to life and property for interior Alaskan residents (Chapin et al. 2008).

South-Central Alaska: South-central Alaska may be particularly sensitive to climate changes because of its confluence of human population growth and changing disturbance regimes (e.g., insects, wildfire, invasive species). Warmer temperatures have contributed to recent spruce beetle (*Dendroctonus rufipennis* Kirby) outbreaks in this region by reducing the beetle life cycle from 2 years to 1 year (Berg et al. 2006, Werner et al. 2006). Higher fuel loads resulting from beetle-caused tree mortality are expected to increase the frequency and severity of wildfires (Berg et al. 2006), which raises societal concerns of increased risks to life and property (Flint 2006). Most goods are shipped to Alaska via ports in south-central Alaska, so invasive plant species will probably become an increasingly important risk factor. Several invasive plant species in Alaska have already spread aggressively into Figure A1-2—In 2004, Alaska's largest wildfire season on record, the Boundary Fire, burned 217 000 ha of forest in interior Alaska. burned areas (e.g., Siberian peashrub [*Caragana arborescens*Lam.], narrowleaf hawksbeard [*Crepis tectorum* L.], and white sweetclover [*Melilotus alba* Medik.]) (Cortés-Burns et al. 2008, Lapina and Carlson 2004), and these could proliferate further with the increase in wildfire potential. Changes in surface hydrology in south-central Alaska have also been linked to warmer temperatures. In the Kenai lowlands, a subregion of south-central Alaska (fig. A1-1), many water bodies have shrunk in response to warming since the 1950s and have subsequently been invaded by woody vegetation (Klein et al. 2005). Recently, the rate of woody invasion has accelerated as a result of a 56-percent decline in water balance since 1968 (Berg et al. 2009). As a result of these combined effects of wetland drying and vegetation succession, wetlands are becoming weak C sources rather than strong C sinks, which has important consequences for the global climate system.

◆ **Wolken, J.M., T.N. Hollingsworth, T.S.Rupp, F.S.Chapin, III, S.F. Trainor, T.M. Barrett, P.F. Sullivan, A.D. McGuire, E.S. Euskirchen, P.E. Hennon, E.A. Beever, J.S. Conn, L.K. Crone, D.V.**

D'Amore, N. Fresco, T.A. Hanley, K. Kielland, J.J. Kruse, T. Patterson, E. A.G. Schuur, D.L. Verbyla, and J.Yarie. 2011. Evidence and implications of recent and projected climate change in Alaska's forest ecosystems. Ecosphere art124. http://dx.doi.org/10.1890/ES11-00288.1

Author abstract. The structure and function of Alaska's forests have changed significantly in response to a changing climate, including alterations in species composition and climate feedbacks (e.g., carbon, radiation budgets) that have important regional societal consequences and human feedbacks to forest ecosystems. In this paper we present the first comprehensive synthesis of climate-change impacts on all forested ecosystems of Alaska, highlighting changes in the most critical biophysical factors of each region. We developed a conceptual framework describing climate drivers, biophysical factors and types of change to illustrate how the biophysical and social subsystems of Alaskan forests interact and respond directly and indirectly to a changing climate. We then identify the regional and global implications to the climate system and associated socio-economic impacts, as presented in the current literature. Projections of temperature and precipitation suggest wildfire will continue to be the dominant biophysical factor in the Interior-boreal forest, leading to shifts from conifer- to deciduous-dominated forests. Based on existing research, projected increases in temperature in the Southcentral- and Kenai-boreal forests will likely increase the frequency and severity of insect outbreaks and associated wildfires, and increase the probability of establishment by invasive plant species. In the Coastal-temperate forest region snow and ice is regarded as the dominant biophysical factor. With continued warming, hydrologic changes related to more rapidly melting glaciers and rising elevation of the winter snowline will alter discharge in many rivers, which will have important consequences for terrestrial and marine ecosystem productivity. These climate-related changes will affect plant species distribution and wildlife habitat, which have regional societal consequences, and trace-gas emissions and radiation budgets, which are globally important. Our conceptual framework facilitates assessment of current and future consequences of a changing climate, emphasizes regional differences in biophysical factors, and points to linkages that may exist but that currently lack supporting research. The framework also serves as a visual tool for resource managers and policy makers to develop regional and global management strategies and to inform policies related to climate mitigation and adaptation.

◆ **Young, B. and A. Ogden. 2010.** Vulnerability and Adaptive Capacity of Yukon Tree Species to Climate Change: Summary Report.*in* Y. G. C. C. Secretariat, editor., Whitehorse, Yukon, Canada.

Author abstract. This summary sets out the key findings from the Vulnerability and Adaptive Capacity of Yukon Tree Species to Climate Change: Technical Report. This report was created as an initial component of a greater study in Yukon on assessing the vulnerability to climate change and adaptive capacity of Yukon forest tree species and ecosystems. The technical report provides a review and a synthesis of current scientific knowledge on the potential vulnerabilities and adaptive capacities of Yukon tree species to climate change.

REFORESTATION MODELING

◆ **Blanco, J.A., Welham, C., Kimmins, J.P., Seely, B., Mailly, D., 2009**. Guidelines for modeling natural regeneration in boreal forests. For. Chron. 85, 427-439.

Author abstract. Natural regeneration is recognized as an important component of forest management. Field studies are usually combined with conceptual and mathematical models as the most effective way to understand and predict natural regeneration. In the case of the boreal forest, several important issues arise in the design of regeneration models and are reviewed here. The most important concerns the trade-off between complexity and portability. Complex models may mimic natural systems more closely than do simpler models, but this realism comes at a cost in terms of the volume of data necessary for their calibration. A second issue is that most regeneration models have been scaled to problems at the tree and stand level, but recent interest in landscape-level issues requires models applicable to this higher spatial scale. Finally, the conceptual framework underlying most regeneration models may need to be revisited in light of recent efforts to depict vegetation dynamics under changing climatic regimes. It is unlikely that any single modeling approach will prove adequate for modeling natural regeneration under all conditions, and we provided guidelines as to how to create effective regeneration models.

◆ **Gray, L. K. and A. Hamann. 2013**. Tracking suitable habitat for tree populations under climate change in western North America. Climatic Change 117:289-303.

Author abstract. An important criticism of bioclimate envelope models is that many wide-ranging species consist of locally adapted populations that may all lag behind their optimal climate habitat under climate change, and thus should be modeled separately. Here, we apply a bioclimate envelope model that tracks habitat of individual populations to estimate adaptational lags for 15 wide-ranging forest tree species in western North America. An ensemble classifier modeling approach (RandomForest) was used to spatially project the climate space of tree populations under observed climate trends (1970s to 2000s) andmulti-model projections for the 2020s, 2050s and 2080s.We find that, on average, populations already lag behind their optimal climate niche by approximately 130 km in latitude, or 60 m in elevation. For the 2020s we expect an average lag of approximately 310 km in latitude or 140 m in elevation, with the most pronounced geographic lags in the Rocky Mountains and the boreal forest. We show that our results could in principle be applied to guide assisted migration of planting stock in reforestation programs using a general formula where 100 kmnorth shift is equivalent to approximately 44m upward shift in elevation. However, additional non-climatic factors should be considered when matching reforestation stock to suitable planting environments.

◆ **Huettmann, F., B. Ohse, and S. Ickert-Bond. 2008.** Distribution of White Spruce in Alaska. An Open Access prediction surface from climatic and bioclimatic parameters using ESRI GRID formats. Data set. **URI:http://hdl.handle.net/11122/2577**

Author abstract. This open access data set contains a spatially gridded distribution of White Spruce in Alaska (ESRI GRID format), predicted from climatic and bioclimatic parameters (temperature, precipitation, elevation, and aspect). A species distribution model, developed by Bettina Ohse, was used to determine the ecological niche of the species based on the environmental variables. The model was developed within TreeNet, a classification and regression tree software. The ecological niche was then projected into geographical space, resulting in a predictive map of the species distribution in Alaska (4km resolution, tested accuracy of c. 95 %). We used ArcGIS 9.2. Data sources were freely available for the global public, and so were all tools used (prediction algorithms and specific GIS tools). We promote these data and this concept as a role model how to model plant distributions in wilderness areas and for overcoming data gaps in species distributions world-wide. We encourage the use and update of these data for further updating of this concept and its findings.

◆ **Liang, J.J. 2012.** Mapping large-scale forest dynamics: a geospatial approach. Landscape Ecology 27:1091-1108.

Author abstract. Digital map of forest dynamics is emerging as a useful research and management tool. As a key issue to address in developing digital maps of forest dynamics, spatial autocorrelation has been distinguished into ‘‘true’’ and ‘‘false’’ gradients. Previous ecological models are mostly focused on either ‘‘true’’ or ‘‘false’’ gradient, and little has been studied to simultaneously account for both gradients in a single model. The main objective of this study was to incorporate both gradients of spatial autocorrelation in a deterministic geospatial model to provide improved accuracy and reliability in future digital maps of forest dynamics. The mapping was based on two underlying assumptions—unit homogeneity and intrinsic stationarity. This study shows that when the factors causing the spatial non-stationarity have been accounted for, forest states could become a stationary process. A prototype geospatial model was developed for the Alaska boreal forest to study current and future stockings across the region. With areas of the highest basal area increment rate projected to cluster along the major rivers and the lowest near the four major urban developments in Alaska, it was hypothesized that moisture limitation and inappropriate human interference were the main factors affecting the stocking rates.

◆ **Liang, J.J., 2010.** Dynamics and management of Alaska boreal forest: An all-aged multi-species matrix growth model. For. Ecol. Manage. 260, 491-501.

Author abstract. Studies on the dynamics of Alaska boreal forest are sporadic and rare, and forest management in the region has been conducted in the absence of a useful growth model. This paper presents a matrix stand growth model to study the dynamics and management of Alaska's boreal forest, with harvests and artificial regeneration being accounted for. The model was calibrated with data from 446 constantly monitored permanent sample plots distributed across interior and south-central Alaska, and was tested to be accurate on an independent validation sample. The present model was applied on a most frequent commercial stand in interior Alaska to study a forest management regime that is being commonly used in the region. The simulation was for 300 years with a 40-year cutting cycle, and management outcomes under various permafrost levels and site elevations were investigated with sensitivity analysis. Despite the comparatively low financial returns, current management regime may generally benefit wildlife species by maintaining continuous forest cover and decent stand diversity, and properly managed forests had potential for timber production and wood-based energy. It was predicted by the model that both permafrost and site elevation had substantial impact on the management outcomes. Other variables being held constant at sample mean, net present value of harvests increased from $434 to $831 ha(-1) and the annual volume of harvest more than tripled from 1.68 to 5.75 m(3) ha(-1) y(-1) as permafrost declined from obvious to unlikely. Managers were also advised to focus on stands on medium elevation (300 m), as stands on lower or higher elevations were expected to produce less harvested volume and net present value. For rural Alaska communities suffering from expensive heating costs, it was suggested that approximately 20 ha of properly managed forest could sustain a household's annual heating requirement, while continuous forest coverage and decent diversity could still be maintained.

◆ **Liang, J. J. and M. Zhou. 2010.** A geospatial model of forest dynamics with controlled trend surface. Ecological Modelling 221:2339-2352.

Author abstract. This paper proposes a method of controlled trend surface to simultaneously account for large-scale spatial trends and non-spatial local effects. With this method, a geospatial model of forest dynamics was developed for the Alaska boreal forest from 446 constantly monitored permanent sample plots. The geospatial component of this model represented large-scale spatial trends in recruitment, diameter growth, and mortality. The model was tested on two sets of validation plots which represented temporal and spatial extensions of the current sample coverage. The results suggest that the controlled trend surface model was generally more accurate than both the non-spatial and conventional trend surface models. With this model, we mapped the forest dynamics of the entire Alaska boreal region by aggregating predicted stand states across the region. it was predicted that under current conditions of climate and natural disturbances, most of the Alaska boreal forest region may undergo a major shift from deciduous-dominant to conifer-dominant, with an average increase of 0.33 m(2) ha year(-1) in basal area over the Twenty-First Century.

◆ **Liang, J. J., M. Zhou, D. L. Verbyla, L. J. Zhang, A. L. Springsteen, and T. Malone. 2011.** Mapping forest dynamics under climate change: A matrix model. Forest Ecology and Management 262:2250-2262.

Author abstract. Global climate change may be affecting forests around the world. However, the impact of climate change on forest population dynamics, especially at the landscape or regional level, has hardly been addressed before. A new methodology was proposed to enable matrix transition models to account for climate impact on forest population dynamics. The first climate-sensitive matrix (CSMatrix) model was developed for the Alaska boreal forest based on observations from over 15 years of forest inventory. The spatially explicit model was used to map climate-induced forest population dynamics across the region. The model predicted that the basal area increment in the region under natural succession would be hindered by global warming, more so for dry upland areas than for moist wetlands. It was suggested that temperature-induced drought stress could more than offset a predicted increase of future precipitation in the region to lower overall forest productivity. At the same time, stand diversity would increase across the region through transient species redistribution. Accounting for climate conditions made the CSMatrix model more accurate than conventional matrix models.

REGENERATION ASSESSMENT AND TECHNOLOGY

◆ **Alaska Department of Natural Resources Division of Forestry.** June 2008. Reforestation Handbook. Unpublished. 31 pp.

Author abstract: This handbook establishes DNR Division of Forestry policies and methods for the planning and evaluation of reforestation under the Forest Resources and Practices Act. It includes standards for regeneration stocking surveys, seedling distribution maps, regeneration survival checks.

◆ **Brand, D.G., Leckie, D.G., Cloney, E.E., 1991.** Forest regeneration surveys: Design, data collection, and analysis. The Forestry Chronicle 67, 649-657.

Author abstract. Regeneration surveys have always been looked on as a necessary evil in silviculture. Huge amounts of data have been collected, only to answer simple questions or to be filed and never used. This paper addresses the possibility of changing regeneration surveys from simple legislative requirements, into components of the forestry information system. Current technology allows the development of sophisticated decision support systems, and this changes the whole perspective on information needed from regeneration surveys. Depending on the level of information needed, ground surveys or aerial surveys can be used. The types of information available from different survey systems are described, and two case studies are presented. In one, regenerating stands are assessed using an intensive ground-based survey and, in the second, the MEIS (Multi-spectral, Electro-Optical Imaging Scanner) is used to identify stocking in young plantations. It is concluded that surveys must be designed by working backwards from the decisions to be made, to the information needed to make those decisions, to the data needed to provide that information.

INDEX

105 Blanco, J.A., C. Welham, J.P. Kimmins, B. Seely, D. Mailly. 2009.
45 Boateng, J.O., J.L. Heineman, J. McClarnon, and L. Bedford. 2006.
46 Boateng, J. O., J. L. Heineman, L. Bedford, G. J. Harper, and A. F. Linnell Nemec. 2009.
69 Boggs K. , M. Sturdy, D.J. Rinella, M.J. Rinella. 2008.
56 Boucher, T. V. 2003.
70 Boucher, T.V., B.R. Mead. 2006.
108 Brand, D.G., D.G. Leckie, and E.E. Cloney. 1991.
4 Brassard, B.W., H.Y.H Chen. 2006.
5 Brown, K. R., D.B. Zobel, and J.C. Zasada. 1988.
5 Burns, R.M. and B.H. Honkala, tech. coordinators. 1990.
25 Byrd, A.G. 2013.
26 Calogeropoulos, C., D. F. Greene, C. Messier, and S. Brais. 2004.
52 Cater, T.C. 1990.
53 Cater, T. C. and F. S. Chapin. 2000.
6 Chrimes, D., 2004..
53 Clautice, S.F. 1974.
26 Cole, E., A. Youngblood, and M. Newton. 2003.
26 Cole, E.C., M. Newton, A. Youngblood. 1999.
65 Collins, William B., and C.C. Schwartz. 1998.
7 Conway, A.J. and R.K. Danby. 2014.
81 Cortini, F., P. G. Comeau, J. O. Boateng, L. Bedford, J. McClarnon, and A. Powelson. 2011.
72 Crossley, D. I. 1956.
46 Crossley, D.I. 1955.
73 Cushing, A. 2005.
81 Danby, R. K. and HIK, D. S. 2007.
27 Densmore, R. V., G.P. Juday, and J.G. Zasada. 1999

Dial, R.J., E.E. Berg, K. Timm, A. McMahon, and J. Geck. 2007.

7 Drake, G.L. 1965
47 Dyrness, C. T., L.A. Viereck, M.J. Foote, J.C. Zasada. 1988.
7 Feng, Zhili, K.J. Stadt, and V.J. Lieffers. 2006.
82 Finkenbinder, M.S., M.B. Abbott, M.E. Edwards, C.T. Landon, B.A. Steinman, B.P. Phinney. 2014
54 Foote, M. J. 1995.
27 Fox, J. 1980

Fresco, N. 2012

28 Gardner, A. C. 1983.
8 Gärtner, S. M., V. J. Lieffers, and S. E. Macdonald. 2011.
82 Gauthier, S., P. Bernier, P.J. Burton, J. Edwards, K. Isaac, N. Isabel, K. Jayen, H. Le Goff, E.A. Nelson. 2014.
47 Gingras, J.-F. 1990.

28 Gradowski, T., V.J. Lieffers, S.M. Landhäusser, D. Sidders, J. Volney, and J.R. Spence. 2010.
2 Graham, J.S., and P.A. Joyner. 2011.
28 Graham, J.S., and T.L. Wurtz. 2003.
111 Gray, L. K. and A. Hamann. 2013.
29 Greene, D.F. and E.A. Johnson. 1998.
8 Greene, D. F., Zasada, J. C., Sirois, L., Kneeshaw, D., Morin, H., Charron, I., and Simard, M. J. 1999.
83 Gundale, M.J., P. Kardol, M.-C. Nilsson, U. Nilsson, R.W. Lucas, D.A. Wardle. 2014.
83 Hamrick, J. L. 2004.
9 Harvey, B.D., Leduc, A., Gauthier, S., Bergeron, Y. 2002.
84 Hogg, E.H. and R.W. Wein. 2005.
29 Hollingsworth, J. 2002.
Holsten, E.H., R.A. Werner, and R.L. DeVelice. 1995.
105 Huettmann, F., B. Ohse, and S. Ickert-Bond. 2008
47 Hunt, J. A. 1988.
9 Hynynen, J., P. Niemistö, A. Viherä-Aarnio, A. Brunner, S. Hein, and P. Velling. 2010.
30 Jandreau, R., and A. Arians. 2006.
84 Johnston, M., S. Webber, G.A. O'Neill, T. Williamson, and K. Hirsch. 2009.
54 Johnstone, J.F. 2008.
30 Johnstone, J. 2005.
55 Johnstone, J.F. 2003.
55 Johnstone, J., L. Boby, E. Tissier, M. Mack, D. Verbyla, X. Walker. 2009.
56 Johnstone, J.F., F.S. Chapin III, J. Foote, S. Kemmett, K. Price, and L. Viereck. 2004.
56 Johnstone, J.F., F.S Chapin, T.N. Hollingsworth, M.C. Mack, V. Romanovsky, M. Turetsky. 2010.
57 Johnstone, J.F., Kasischke, E.S., 2005.
57 Johnstone, J.F., E.J.B. McIntire, E.J. Pedersen, G. King, and M.J.F. Pisaric. 2010
58 Johnstone, J.F., Rupp, T.S., Olson, M., Verbyla, D. 2011.
10 Juday, G.P. 2013.
31 Juday, G.P. 2005.
85 Juday, G.P., V. Barber, E. Berg and D. Valentine. 1999.
71 Juday, G.P., V. Barber, P. Duffy, H. Linderholm, S. Rupp, S. Sparrow, E. Vaganov, and Werner, R.A. 2002.
85 Juday, G.P., V. Barber, S. Rupp, J. Zasada, M.W. Wilmking. 2003.
85 Juday, G.P., V. Barber, E. Vaganov, S. Rupp, S. Sparrow, J. Yarie, H. Linderholm, E. Berg, R. D'Arrigo, P. Duffy, O. Eggertsson, V.V. Furyaev, E.H. Hogg, S. Huttunen, G. Jacoby, V.Ya. Kaplunov, S. Kellomaki, A.V. Kirdyanov, C.E. Lewis, S. Linder, M.M. Naurzbaev, F.I. Pleshikov, Yu.V. Savva, O.V. Sidorova, V.D. Stakanov, N.M. Tchebakova, E.N. Valendik, E.F. Vedrova, and M. Wilmking. 2005.
31 Juday, G.P., R.V. Densmore, and J.C. Zasada. 2013.

15 Metslaid, M., Jogiste, K., Nikinmaa, E., Moser, W.K., Porcar-Castell, A. 2007.
33 Murray, M. 1980.
33 Newton, M. 1997.
33 Newton, M. 1996.
34 Nichols, T.F. 2005.
60 Nilsson, M.C., 1998.
51 Norman, C.M. 1978.
92 Okano, K. 2012.
93 O'Neill, G.A., N.K. Ukrainetz, M.R. Carlson, C.V. Cartwright, B.C. Jaquish, J.N. King, J. Krakowski, J.H. Russell, M.U. Stoehr, C-Y. Xie, and A.D. Yanchuk. 2008.
93 O'Neill, G.A., M.R. Carlson, V. Berger, and A.D. Yanchuk. 2007.
2 Ott, R.A. 2005.
35 Packee, E.C. 2001.
35 Packee, E.C. 1999.
35 Packee, E.C. 1997.
49 Packee, E. C. 1990.
61 Paragi, Thomas F. and Haggstrom, Dale A. 2007.
34 Paquette, A., A. Bouchard, and A. Cogliastro. 2006.
94 Pedlar, J.H., D.W. McKenney, I. Aubin, T. Beardmore, J. Beaulieu, L. Iverson, G.A. O'Neill, R.S. Winder, and C. Ste-Marie. 2012.
94 Pedlar, J., D. McKenney, J. Beaulieu, S. Colombo, J. McLachlan, and G. O'Neill. 2011
35 Peltzer, D.A., Bast, M.L., Wilson, S.D., Gerry, A.K., 2000.
36 Perala, Donald A., and Alm, Alvin A. 1990..
36 Peters, V.S., S.E. Macdonald, and M.R.T. Dale. 2006.
61 Peters, V.S., S.E. Macdonald, and M.R. T. Dale. 2005.

Potkin, M. 1997

94 Price, D.T., R.I. Alfaro, K.J. Brown, M.D. Flannigan, R.A. Fleming, E.H. Hogg, M.P. Girardin, T. Lakusta, M. Johnston, D.W. McKenney, J.H. Pedlar, T. Stratton, R.N. Sturrock, I.D. Thompson,[c] J.A. Trofymow, L.A. Venier. 2013.
2 Puettmann, K.J., Ammer, C., 2007.
66 Pusenius, J. and R.S. Ostfeld. 2002.
37 Putman, W.E. 1986.
37 Putman, William E. and Zasada, John C. 1986.
67 Putman, W.E., and J.C. Zasada. 1985.
62 Rees, Daniel C., Juday, G.P. 2002.
67 Richmond, A.P. 1985.
49 Richmond, A. and T. Malone. 1986.
95 Robertson A.L. 2012.
15 Roessler, J.S. 1997.
96 Roland, C.A., J.H. Schmidt, and J.F. Johnstone. 2013.

96 Roland, C.A., J.H. Schmidt, and E.F. Nicklen. 2013.

16 Rossi, S., Tremblay, M.J., Morin, H., Savard, G., 2009.

97 Rowland, E.L. 1997.

102 Sanders, T. 2011.

37 Sanders, R.C. 2003.

Schrader, B. and P. Hennon (compilers). 2005.

62 Schulze E.D., Wirth C., Mollicone D., Ziegler, W. 2005.

16 Shaw, J.D. 1994.

52 Smith, G.K.M. 1988.

74 Spellman, K.V. , C.P.H. Mulder, and T.N. Hollingsworth. 2014.

38 Sprankle, J. and W. Putman. 2002.

97 Tape, K. 2011

17 Taylor, A.R., Chen, H.Y.H., 2011.

17 Taylor, R. F. 1934.

38 Timothy, C. 1990.

38 Tousignant, D. 1995.

98 Ukrainetz, N.K., G.A. O'Neill, and B. Jaquish. 2011.

99 Van Cleve, K., W.C. Oechel, and J.L. Hom 1990.

38 van Hees, Willem W.S. 2005.

74 Villano, K.L. 2008.

17 Vogt, S.L. 2002.

39 Wahrenbrock, W. 2014.

99 Walker, X., and J.F. Johnstone. 2014.

100 Wang, T., E.M. Campbell, G.A. O'Neill, and S.N. Aitken. 2012.

63 Wardle, D.A., Zackrisson, O., Nilsson, M.C. 1998.

100 Wendler G., M. Shulski. 2009.

71 W**erner, R.A., E.H. Holsten, S.M. Matsuoka, and R.E. Burnside. 2006.**

49 Wiensczyk, A., K. Swift, A. Morneault, N. Thiffault, K. Szuba, and F. W. Bell. 2011.

101 Williamson, T.B.; S.J. Colombo, P.N. Duinker, P.A. Gray, P.A, R.J. Hennessey, D. Houle, M.H. Johnston, A.E. Ogden, D.L. Spittlehouse. 2009.

18 Wilmking, M. 2003.

102 Wilmking, M., G.P. Juday, V. Barber, and H. Zald. 2004.Wurtz, T.L. 2000.

102 Wilmking M., G.P. Juday, M. Terwilliger, and V. Barber. 2006.

68 Wimberly, M. C. and Z. Liu. 2013.

18 Winslow, S.E. 2008.

Wolken, J.J. and T.N. Hollingsworth. 2012.

103 Wolken, J.M., T.N. Hollingsworth, T.S.Rupp, F.S.Chapin, III, S.F. Trainor, T.M. Barrett, P.F. Sullivan, A.D. McGuire, E.S. Euskirchen, P.E. Hennon, E.A. Beever, J.S. Conn, L.K. Crone, D.V. D'Amore, N. Fresco, T.A. Hanley, K. Kielland, J.J. Kruse, T. Patterson, E. A.G. Schuur, D.L. Verbyla, and J.Yarie. 2011.

39 Wurtz, T.L. 2000.
19 Wurtz, T.L. 1988.
40 Wurtz, T.L., Zasada, J.C. 2001.
104 Young, B. and A. Ogden. 2010.
19 Young, B. D. 2012.
20 Young, B., J. Liang, and F. Stuart Chapin. 2011.
21 Youngblood, A.P. 1995.
40 Youngblood, A.P. 1990.
50 Youngblood, A., E. Cole, and M. Newton. 2011.
40 Youngblood, A.P., and T. A. Max. 1992.
41 Youngblood, A.P., and J.C. Zasada. 1991.
41 Zasada, John. 1990.
22 Zasada, J.C. 1988.
41 Zasada, J.C. 1986.
22 Zasada, J.C. 1984.
42 Zasada, J.C. 1978.
42 Zasada, J.C. 1972.
21 Zasada, J.C. and Gregory, R.A. 1972.
43 Zasada, J.C. and Gregory, R.A. 1969.
64 Zasada, J. and Norum, R. 1986.
64 Zasada, J.C., R.A. Norum, R.M. Van Veldhuizen, C.E. Teutsch. 1983.
23 Zasada, J.C., and G.A. Schier. 1973.
21 Zasada, J.C., T.L. Sharik and M. Nygren. 1993.
41 Zasada, J. C.; Slaughter, C.W.; Teutsch, C.E.; Argyle, J. D.; Hill, W. 1987.
43 Zasada, J. C., L.A. Viereck, M.J. Foote, R.H. Parkenson, J.O. Wolff, L.A. Lankford Jr. 1981.